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Intelligence

Maria Voyatzaki

Technology has always been responsible for the profound transformation of the cultures that developed it. Technological advancements introduce new cognitive and symbolic systems which, however, are not readily apparent as soon as new technologies are developed. It always took longer -even as long as generation lifespans- to assimilate, exploit and turn into practices the cognitive possibilities opened up by any technological innovation ¹. If it is valid to suggest that cultural evolution follows technological evolution, then we can safely assume that we are far from the complete exploitation of the cognitive mutations we are experiencing or encountering in the new technological environment formulated by the recent advancements of communication networks and information processing technologies. However, we can already detect an emergent (social) agenda of humanity which strives for the extension of life from the organic to the inorganic realm, shifting from what we used to call natural processes to what we now understand as intelligent design².

The notion of intelligence has become a buzzword that accompanies every possible action, praxis, process or product nowadays. Its dominance in contemporary thinking and practice is grounded on two new and closely related considerations. The first is the ontological mutation of intelligence, from its conception as the exclusive function of the human brain to its definition as a property emerging from a specific set of conditions in which a human or a non-human organism or machine could exist. Intelligence is no longer only a human privilege. The second is the understanding of intelligence not as the outcome of the function of one single organ or center but as the emergent property of the symbiosis and the respective interaction between a 'brain' (human or non-human), a body and the environment(s) in which this body exists. There is an inseparable continuity between any kind of mind and body, body and environment, mind and matter, intelligence and environment.

This mutation renders intelligence a symbolic reference of an emerging -if not already established- understanding of the human as part of a new worldview. According to this understanding, the humans are, no longer, the most important and capable distinct beings in the universe having always an antagonistic re-

1. Pierre Lévy set as an example the print technology which 'fostered the development and progressive formalization of linguistic studies and the creation of metadata systems for the organization of libraries and archives'. Cf. Lévy, P. (2010). From social computing to reflexive collective intelligence: The IEML research program. In: International Journal for Information Sciences, Volume 180, Issue 1, 2, January 2019. Elsevier pp.72.

2. A presentation of this new agenda to the broader public could be considered the case of Harari, Y.N. (2016). Homo Deus. A brief History of Tomorrow. Harvill Secker, London, UK.

lationship with their natural environment. They are conceived as embodied in an extended interconnected and networked technological world. The humanitarian rationalism discarded God from the center of the social imaginary to glorify the human intelligence in its perpetual conflict with nature. Posthuman thinking discards the humans from their believed dominance to glorify the planetary intelligence of the living Gaia³. Any form of intelligence, human or non-human, is now considered as dynamically interdependent. Any individual intelligence, alive or machinic, is part of a collective alien intelligence.

Intelligence, nowadays, underlies notions of control, management, efficiency, but also notions of sensing, abstracting, learning, deciding and acting in either a human or in a non-human manner. In other words, it encompasses all aspects of design, introducing a new design intelligence utterly different from the one generated by the human-centered approaches to creation. It perpetually moves between the effective and smart management of presented resources and the spontaneous creation of smart environments that afford and encourage the participation of anything that could be called user, being it human or non-human.

The shift in the conception of intelligence, profoundly affects the contemporary understanding of design of the built environment at any scale and every stage of the design process. We are facing new theorisations and actualisations of the concepts of innovation, creativity, and imagination, three of the main driving forces of the design activity.

Innovation has always been a primary goal of the design of the built environment around which, all human-centered theoretical discourses developed their intellectual foundations to assist the creation of innovative design outcomes. As theory is primarily based upon values, there is always a directed articulation of existing elements towards new and innovative combinations. The development of advanced computation and networking technologies and tools, supported by, and supporting the aforementioned posthuman understanding of the self and the world, expect the collective alien intelligence to open up new directions to innovation. In this context, innovation is no longer considered as the creation of something just entirely new. It is the request for unpredictably unexpected and unthinkable associations and speculations of existing components which were hidden, latent, separated or isolated and conceived as irrelevant by the different theoretical doctrines occasionally dominating the design of the built environment. The request for the 'radically new',⁴ is

3. For a socio-philosophical presentation of the posthuman see Pepperell, R. (2003). *The Posthuman Condition: Consciousness beyond the Brain*. Intellect Books, Portland Oregon, USA and Braidotti, R. (2013). *The Posthuman. The Polity*, London. For a techno-philosophical approach to the posthuman see Hayles, K. (1999) *How we have become Post-Human: Virtual Bodies in Cybernetics, Literature, and Informatics*. The University of Chicago Press, Chicago USA.

4. For a concise investigation of the nature and the adventures of the request for novelty and its relationships with the old see North, M. (2013). *Novelty: A History of the New*. University of Chicago Press, Chicago, USA.

supported by the harsh critiques appearing twenty years ago, to pre-existed theories, defining them as an impediment to the development of an innovation culture in design⁵ which has to be replaced by a new intellectual framework supporting rather than inhibiting innovation.

The human-centered paradigm conceives creativity as one of the distinctive attributes of human consciousness such as intelligence, thought, emotion, memory, imagination, awareness, self-knowledge, sense of being. Through psychology, creativity was explained, among others, as a brain function connecting incentives from the two lobes of the brain⁶ (Braian Lawson). This can explain the enhancement of creativity linked to the enrichment of external stimuli which could eventually intensify these connections. In the post-human context, creativity is a faculty inseparable from intelligence. As intelligence is primarily based upon pattern recognition and categorisations (abstraction) as well as hierarchical classifications (association), creativity is conceived as a quality of intelligence, assessed by the operational value of the emergent new abstractions and new pattern associations in thinking processes. Since intelligence emerges from specific sets of conditions in the human and non-human continuum mind-body - environment(s), the presence of abstractions assured by the non-human intelligence, devoid of values and prejudices, constitutes a critical factor for new associations of creative intelligence.

Humanists consider prediction as one of the main traits of human consciousness, closely related to our sense of time. Prediction and even more scientific prediction is formed upon human logic. The dynamics and the complexity of the mind-body-environment(s) continuum, render prediction done by humans a somewhat questionable guide for the creation of reality. Not just because it can only be short-term, but mainly because it is based upon preexisting human stereotypes, established prejudices, actual conflicts or entrenching. Imagination, and more specifically, collective imagination is proposed as a fair alternative for the production of reality. Collective imagination, as an attribute of collective intelligence, is conceived as a vehicle towards an unpredictable and not yet 'written' future, which optimistically connotes that we are probably much more liberated than we think; a vehicle for a shift from rational thinking to speculative thinking, that by no means is an invitation to abandon our critical faculties, value references, and socio-cultural standings. On the contrary, the recourse to collective imagination is an encouragement to creatively and efficiently use the powerful tools provided by digital technologies. Pierre Levy reminds us

5. Cf. Speaks, M. (2005). *After Theory*. In: *Architectural Record Magazine*, June 2015. New York pp 72-75.

6. Cf. Lawson B. (1980). *How Designers Think. The Design Process Demystified*. Architectural Press, Oxford.UK

that the significant advances in human cognition are related to inventions of media and symbolic systems. We are facing the challenge to enhance our personal and collective cognitive abilities by engaging ourselves in various intellectual cooperations to invent, innovate and create the new human reality in the 'new reterritorialised agora' of cyberspace⁷ and the techno-cultural world of the post-human era.

All the above statements, ideas, and thoughts are to be tested and critically assessed as to their operability, ethics, and tactics. Research in this emergent field is facing a significant challenge and requires at least a provisional cognitive mapping. This archIDOCT issue, in its effort to contribute to this mapping, invited doctoral research essays focusing on any field related to architecture and the city, where intelligence is mobilised at any scale and stage of its theorisation and actualisation. Authors were encouraged to construct arguments for or against any idea of intelligence in general and in design in particular. The issue includes one good practice example and five essays by doctoral students worldwide.

The good practice example has been kindly offered to our issue by Professor Nicos Komninos from Aristotle University of Thessaloniki. The essay originates from a book he authored in 2015 with Routledge with the title *The Age of Intelligent Cities: Smart Environments and Innovation-for-all Strategies*. The book is the last part of a trilogy on the theme of Intelligent Cities. The current essay entitled *Alternative Architectures of Spatial Intelligence of Cities: Pathways to Innovation* continues an argument that suggests that 'the intelligence of cities is based on a series of knowledge functions which are collectively created and deployed, such as network-based information intelligence and forecasting, technology learning and acquisition, collaborative innovation, product and service promotion and dissemination'. The essay is a continuation of these arguments through an appreciation of the different forms of spatial intelligence that are activated by arrangements of knowledge functions and infrastructure into cities. The concept of spatial intelligence of cities and a quick overview of the literature on cyber, digital, intelligent, and smart cities, which points to different types of spatial intelligence, are described. The four trajectories and architectures of spatial intelligence -agglomeration, orchestration, empowerment, and instrumentation- that can be found within cities follow. Cases studies from Bletchley Park UK, Cyberport Hong Kong, Smart Santander and Amsterdam Smart City illustrate the above types of spatial intelligence. These socio-technological experiments highlight important efforts to create intelli-

7. Cf. Lévy, P. (2006). *Collective Intelligence, A Civilisation: Towards a Method of Positive Interpretation*. International Journal of Politics, Culture, and Society, Vol. 18, No. 3/4, The New Sociological Imagination (Spring - Summer, 2005). Springer, pp. 189-198.

gent places and contribute to a better understanding of the many faces of spatial intelligence. Last but not least, the essay attempts to draw a synthesis of the different types of spatial intelligence by defining a universal architecture, based on variables such as the type of knowledge functions activated (information gathering, technology learning, innovation, dissemination), the type of intelligence used (human, organisational, artificial), and the type arrangements within the urban space in processes takes place.

The first essay by Alexander Liu Cheng is entitled Machine Learning as enabler of Design-to-Robotic-Operation. Alexander is a PhD candidate at Robotic Building, Faculty of Architecture and the Built Environment, TU Delft (Delft, The Netherlands); and Adjunct Professor / Researcher at Facultad de Arquitectura e Ingenierías, Universidad Internacional SEK (Quito, Ecuador). His essay promotes Artificial Intelligence via Machine Learning ML as a fundamental enabler of technically intelligent built-environments. It does this by detailing ML's successful application within three deployment domains: (1) Human Activity Recognition, (2) Object as well as Facial-Identity and -Expression Recognition, and (3) Speech and Voice-Command Recognition. With respect to the first, the essay details previously developed ML mechanisms implemented via supervised classifiers capable of recognising a variety of physical human activities. With respect to the second, it details three previously developed ML mechanisms implemented individually via (i) BerryNet—for Object Recognition; (ii) TensorFlow—for Facial-Identity Recognition; and (3) Cloud Vision API—for Facial-Expression Recognition. Finally, and with respect to the third, it details a presently developed ML mechanism implemented via Cloud Speech-to-Text that enables the transcription of spoken speech—in several languages—into string text used to trigger pertinent events within the built-environment. The sophistication of the so-called Machine Learning collectively imbues the intelligent built-environment with a continuously and dynamically adaptive character that is central to Design-to-Robotic-Operation, which is the Architecture-informed and Information and Communication Technologies-based component of a Design-to-Robotic-Production and Operation framework.

George Tryfonos currently conducting his PhD research at the University of Cyprus that focuses on industrial robotics and fabrication with tensile – high elastic materials in architecture has contributed to this issue with an essay entitled Automated robotic toolpath generation of elastic mesh structure. An additive waving techniques for form-finding, MOGA optimisation, and robotic fabrication. The essay describes the development

of an automated robotically-driven algorithm that can be used for the design, simulate and robotic fabrication of elastic tensile mesh structures. This approach aims to automate the process between design development and additive fabrication phases through the development of a custom-made end-effector tool for physical execution. Specifically, the suggested procedure explores a weaving elastic mesh technique, followed by an automated form-finding and static analysis investigation as well as a direct toolpath generation implemented by an industrial robotic fabrication process. Within this framework, a feedback loop between the form-finding and optimisation algorithm is investigated, which is responsible for controlling the pretension of the elastic threads, aiming to suggest optimum additives robotic tool-paths. In parallel, robot's and end-effector tool's parameters and limitations are taken into account during digital form-finding and optimisation processes. The suggested procedure aims to extend the automated robotically-driven algorithm in order to achieve accurate repeatability control of the elastic material and in turn the effective physical fabrication of complex tensile shapes.

Valerio Perna is the author of the essay entitled Urban Environment from Smart Cities to Playable Cities. Towards Playful Intelligence in the Urban Environment. Valerio Perna is a PhD student at Roma, La Sapienza School of Architecture. As the author suggests, in the last decade, we have seen the rise of urban play as a tool for community building and city-making, and Western society is actively focusing on play/playfulness and intelligent systems as a way to approach complex challenges and emergent situations. In this essay, Valerio Perna aims to initiate a dialogue between game scholars and architects. Like many creative professions architectural practice may benefit significantly from having more design methodologies at hand, thus improving lateral thinking. Perna also aims at providing new conceptual and operative tools to discuss and reflect on how games and smart systems facilitate long-term the shift from the Smart Cities to the Playable one, where citizens/players have the opportunity to hack the urban fabric and use the smart city's data and digital technology for their purposes to reactivate the urban environment.

The essay entitled Architectural Intelligence is authored by Andreea Movila a PhD Student at Ion Mincu University of Architecture Bucharest. The essay documents and substantiates the notion of Architectural Intelligence, which does not refer to the emerging talks about Building Intelligence, but to the neuroscience of architecture, and what we can understand about

the brain of the architect as he or she designs a building. In the first instance of the study, intelligence is properly situated within the structures of mental organization and then the relationship between the architectural intelligence -perceived as a cumulus of specific mental abilities- and the architectural thinking -as an action, the mental manipulation of the information- is analysed. The premises for an Architectural Intelligence Theory are given by the context of the Theory of Multiple Intelligences developed by the psychologist Howard Gardner that suggests that there are have several types of intelligence - (musical-rhythmic, visual-spatial, verbal-linguistic, logical-mathematical, body-kinesthetic, interpersonal + intrapersonal = emotional) and not a single general intelligence- as perceived until then (the g factor proposed by the psychologist Charles Spearman in the early years of the 20th century). Following Howard's criteria, Andreea has documented the inclusion of Design Intelligence in the realm of the Theory and has developed the connection with Architectural Intelligence as an associated construct. Architect's relationship with the world has always been constantly changing throughout history and the most pertinent question to be answered today is how we can still remain relevant in a world of fantastic changes in which the field limits are subtly absorbed by other domains. The purpose of the study is to question how the role of architecture has been evolving over time, from its primary concern as need for representativeness to nowadays unquantifiable realms that imprint the delicate relation to the new paradigm of artificial intelligence.

Last but not least, the essay by Artemis Psaltoglou, an Architect Engineer whose research focuses on urban planning, spatial development and participatory processes, and a PhD candidate at the Department of Urban and Regional Planning (AUTh) is entitled "From Smart to Cognitive Cities: Intelligence and Urban Utopias". The essay elaborates on recent approaches in human intelligence that have provided us with a broader understanding about its multiplicity and its dynamic nature. As the essay argues the human capacity to imagine beyond the existing has led to the creation of utopias as a way to fantasize about future societies and future cities. The current essay explores how the concept of intelligence is reflected in urban utopias. More specifically, it focuses on two current urban utopias, which are the predominant urban visions for the digital era: Smart and Cognitive cities. The vision of smart cities, grounded in the intensive use of information and communication technologies (ICT) for the sustainable development of cities, gained a lot of popularity and a wide range of smart city initiatives have been implemented across the world. Apart from the criticism for the technological determinism of

smart cities and for endorsing a corporate vision of cities, it is argued that the dominant approach of smart cities considers intelligence as a prime technological function. Based on advances in cognitive computing, cognitive cities expand the concept of smart cities through the introduction of cognition and learning. The essay concludes with some thoughts on intelligence and the function of utopian thinking, and underlines the role of technology as one among many interrelated elements that compose our cities.

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Architectures Of Intelligence In Smart Cities: Pathways To Problem-Solving And Innovation

Nicos Komninos

Abstract

The discussion about intelligence and problem-solving capabilities has flourished in the literature of smart cities, under concepts such as spatial intelligence, connected intelligence, ambient intelligence, collective intelligence, new intelligence of cities, city smartness, and other. In this paper we take a quick overview of the literature that points to different types of intelligence into digital, smart, and intelligent cities. We then describe four architectures of intelligence (agglomeration, orchestration, empowerment, and instrumentation) that appear within smart city ecosystems. Cases studies from Bletchley Park UK, Cyberport Hong Kong, Smart Santander, and Amsterdam Smart City illustrate the above typology. These socio-technological experiments contribute to a better understanding the many faces that intelligence appear into smart cities, linking humans, organisations, and machines. In the last section, we attempt a synthesis by defining a universal architecture of city intelligence, based on variables such as the knowledge functions activated, the origin of intelligence used, and the connectivity between the digital and non-digital entities of the urban space.

Keywords

City intelligence, Spatial intelligence, Connected intelligence, Empowerment, Innovation, Governance

Note

A previous version of this paper has been published in Komninos, N. (2014). The Age of Intelligent Cities. Smart Environments and Innovation-for-all Strategies, Routledge: London and New York, chapter 4. It is published here with a few modifications.

Introduction: What makes cities intelligent?

The new interdisciplinary paradigm of 'intelligent cities' or 'smart cities' bringing together theories, methodologies and practices from diverse fields, such as urban development, strategic planning, web and Internet technologies, engineering, knowledge and innovation management, is overturning established urban development and planning practices. The impact of this paradigm reaches far beyond the domain of cities as it influences the way we address global challenges of competitiveness, sustainability and climate change, employment and inclusion.

A very rich literature reflects the evolution of thinking and practice in the field of digital - intelligent - smart cities and outlines the contribution of information technologies and innovation processes to the development and planning of 21st century cities. From Mitchel (1996), Ishida and Isbister (2000) and Graham (2003) focusing on technologies, experiences, and case studies of digital cities, to Komninos (2002, 2008, and 2014), Bell et al. (2009) on intelligent cities and the nexus of ICTs, collective intelligence and innovation, to Caragliu et al. (2009), Belissent (2010), Deakin (2011), Schaffers et al. (2011) on smart cities, embedded systems and the future Internet, and Aggelidou (2015) and Chourabi et al. (2012) on forces shaping smart cities, this literature also highlights a trajectory of change. It describes the continuous evolution of digital technologies and innovation systems that feed intelligent cities and the creation of more open and innovative urban ecosystems deployed over the digital, social and physical space of cities. Such ecosystems enable citizens, end-users, enterprises and organisations to develop innovative behaviour, become more competitive and resource efficient, and more intelligent in decision-making.

Despite the great diversity of strategies and solutions that can be observed, intelligent and smart cities rely on a core of knowledge processes (Komninos, 2008). We call this core 'spatial intelligence of cities'. Spatial intelligence is made by informational, cognitive and innovation processes, which take place within cities and enable citizens and organisations to more efficiently address the challenges they face. It refers to the ability of a community or a city to combine its intellectual capital, institutions for collaboration, and smart infrastructure for setting up knowledge functions that optimise the use of resources in a wide range of city sectors and challenges.

Spatial intelligence is the ingredient that makes cities intelligent. Having said this, the aim of this paper is to discuss different architectures and trajectories that make spatial intelligence emerge. Furthermore, the aim is to describe the fundamental variables of spatial intelligence and how they change along the evolution that takes place in digital technologies and innovation systems. In previous publications (Komninos, 2008 and 2014) we have argued that the intelligence of cities is based on a series of knowledge functions which are collaboratively created and deployed, such as network-based information intelligence and forecasting, technology learning and acquisition, collaborative innovation, product and service promotion and dissemination. Here, we extend these arguments by showing how different forms of spatial intelligence are activated by arrangements of knowledge functions, source of capabilities, infrastructure and connectivity into cities.



Intelligence in the smart city literature

In smart cities, intelligence emerges from the agglomeration and integration of three types of intelligence: human intelligence, the inventiveness, creativity and intellectual capital of the city's population; collective intelligence, organised by the city's organisations and institutions, relying on rules for collaboration and social capital; and machine intelligence offered by public and city wide smart infrastructure, virtual and smart environments, and ambient intelligence (Kominos, 2008, 122-123). These forms of intelligence are interconnected. Using spatially combined intellectual capacities, individual skills and organisational learning, smart cities can respond more effectively to changing socio-economic conditions, address challenges, optimize operations, plan more accurate for the future, and sustain the prosperity and well-being of citizens.

Thus, the intelligence of smart cities is based on informational and cognitive processes, such as information collection and processing, real-time alert, evidence-based decision-making, forecasting, learning, awareness, distributed problem-solving, co-creation and collaborative innovation that take place in cities. We may call it 'spatial intelligence', pointing out to space and agglomeration as preconditions of its appearance.

Collaboration has been a major driver of the spatial intelligence of cities. Partnerships, collaboration platforms and social networks nurture the development of technologies, skills, and learning. Social media have contributed enormously via crowdsourcing platforms, mash-ups, web-collaboration, and other means of participatory and distributed problem-solving. Media technologies and collaborative platforms remain a key instrument for connecting different types of intelligence into spatial agglomerations. However, the recent turn towards smart cities and systems highlight other routes as well. The widespread of Internet technologies promoting cloud-based services, the Internet of Things, the use of smart phones and smart meters, networks of sensors and RFIDs, analytics and more accurate semantic search, open new ways to connectivity and collaborative problem-solving.

The literature on digital, intelligent and smart cities, which spans a period of twenty years, highlights different forms of spatial intelligence which appeared with respect to different web technologies, knowledge and innovation processes, and forms of community engagement. Since the 1980s, urban development has been linked to innovation ecosystems, technology-driven localities, innovation clusters, and creative hubs, in which R&D, knowledge, and innovation were connected by agglomeration and locality. In the 1990s, a new digital spatiality started expanding over the physical and institutional space of cities. However, ICTs, the Internet and the web alone would not have had a strong impact on cities if contemporary urban agglomerations had not rooted their development in knowledge and innovation. In the 1990s a digital spatiality joined the spatiality of cities in multiple ways, enhancing communication, city representation, virtualisation of infrastructures, transforming urban activities, optimisation of city functions, and enabling more participatory governance. These different roles of the digital space and the different forms of integration between physical, institutional and digital spaces gave birth to different forms of spatial intelligence within 'cyber', 'digital', 'intelligent', and 'smart' city environments.

Cyber-intelligence: The cyber literature marked the initial stage of the digital trajectory of cities. Cybercities and cyberspace refer to any type of virtual space generated by a collection of data within the Internet (Shiode, 1997), but the concept also contains the sense of inspection and control with communication and information feedback as preconditions of effective action. It carried some seeds from the ideas of cybernetics that appeared in the 1940s on communication with machines

and feedback loops in decision-making. This perspective led to early e-government applications for city management and more recently to technologies for security and control over the urban space, and in some cases the transfer of military methods of tracking, identification and targeting into the governance of urban civil society (Graham, 2010). In a broader sense, a Cybercity is conceived as a web-based city in which people interact with each other through and exclusively over the cyber space. Antorroiko (2005) points out that the 'cyber' prefix refers also to the dark side of the virtual space, to 'cyberterrorism' and 'cyborg' dimensions.

Representational intelligence: A more neutral discussion opened within the digital city literature with the work of Ishida and Isbister (2000), Hiramatsu and Ishida (2001), Van den Besselaar and Koizumi (2005). It concerned the representation of the city, in early forms via portal-type webpages, panoramic and 3D representations of cities, and later with augmented reality technologies, and urban tagging. Digital cities are connected communities that combine "broadband communications infrastructure; a flexible, service-oriented computing infrastructure based on open industry standards; and innovative services to meet the needs of governments and their employees, citizens and businesses" (Yovanof and Hazapis, 2009). The digital city is a metaphor of the city: an understanding of the city through its virtual representation. Digital cities were described as 'mirror-city metaphors', as their logic was to offer "a comprehensive, web-based representation, or reproduction, of several aspects or functions of a specific real city, open to non-experts" (Couclelis, 2004). The spatial intelligence related to solutions of this type was based on advantages of representation and visualisation. "A picture is worth a thousand words" reflects this idea that complex environments can be described and understood better via a virtual representation or visual metaphor.

Collective intelligence: The discussion about city intelligence emerges also at the crossroads between the knowledge-based development of cities (knowledge cities) and the digital cities of media. These perspectives offer quasi-similar understandings of city intelligence. Mitchell attributes city intelligence to a combination of telecommunication networks, sensors and tags, and software improving the knowledge and cognitive competences (Mitchell, 2007). City intelligence comes from partnerships and social capital in organising the development of technologies, skills, and learning, and engaging citizens to become involved in creative community participation (Deakin and Allwinkle, 2007). The intelligence of cities is based on a combination of the creative capabilities of the population, knowledge-sharing institutions, and digital applications organising collective intelligence, which altogether increase the ability to innovate that is the ultimate indication of intelligence. Thus, the spatial intelligence of cities builds on collective intelligence, web 2.0 solutions for user engagement, and social capital for collaboration (Segaran, 2007). It is based on people-driven innovation and experimental environments supporting the principles of openness, realism, and empowerment of users in the development of new solutions (Bergvall-Kåreborn and Ståhlbröst, 2009).

Intelligence into data: The recent turn towards -and interest in- smart systems and cloud computing link city intelligence to data provided by the Internet, smart phones, smart devices, sensors, RFIDs, social media, and the Internet of Things. Smart city solutions on the cloud (Kakderi et al., 2016; Tsarchopoulos et al., 2016) using sensors and smart devices improve the ability to gather information, forecast and manage urban activities and flows, and advance city intelligence (Chen-Ritzo et al., 2009). Within this environment, spatial intelligence moves out of applications and enters the domain of data: the meaning of data becomes part of data, affluent data are provided in real-time, real-time data enable real-time response, analytics, and more informed-decisions.

Critical questions within this large landscape of practices for digital transformation concern the



sources of the spatial intelligence of cities: the structures, mechanisms and architectures that sustain the problem-solving capability of cities. What makes a city intelligent or smart? Which type of spatial intelligence is activated within each district and sector of the city? Is it a spatial intelligence common to all districts or are different structuring forms activated within different city districts depending on their functional characteristics and governance?

Four architectures of intelligence in smart cities

We discuss these questions with respect to case studies from Bletchley Park UK, Cyberport Hong Kong, and Smart Amsterdam, and the corresponding forms of spatial intelligence. We start from the baseline, intelligence created by the agglomeration of applications, and then we present three forms of spatial intelligence which rely on different arrangements and connectivity within the urban space. The case studies show that spatial intelligence of cities takes many different forms and follows diverse trajectories as well. The variable connections between the digital, social and physical space of cities, and the large number of digital applications gathered over cities actualise many mechanisms that both give structure to and sustain city intelligence. These forms are orchestration intelligence, which is based on collaboration and distributed problem-solving within a community having full control over information and knowledge processes; empowerment intelligence, which is based on people's competences through up-skilling provided by experimental facilities, open platforms and city infrastructure; and instrumentation intelligence, based big data, real-time information, data analytics, and predictive modelling for better decision-making across city districts and utilities. These trajectories of spatial intelligence can work in isolation or in a complementary way. They provide different ways of problem-solving, but always taking place with networks and connections between the physical, institutional, and digital space of cities.

(i) Baseline: Agglomeration intelligence through connected variety

From the moment they emerged, cities were based on advantages created by spatial proximity, the division of labour and collaboration, use of common infrastructure, face-to-face communication, the development of trust and alliance. The spatial agglomeration of people, activities, and buildings was made possible by advances in the division of labour and exchange of goods, and in turn generated a series of positive social and economic externalities. Soja (2003), writing about the first urban settlements and cities insists on "putting cities first", attributing to Synekism -the physical agglomeration of people with a form of political coordination- the capacity to advance creativity, innovation, territorial identity, and societal development which arise from living in dense and heterogeneous agglomerations.

Soja refers extensively to "The Economies of Cities" by Jane Jacobs (1969) and the findings at Catal Huyuk, the largest and most developed early city in southern Anatolia, where Jacobs located major innovations and transformations from hunting and gathering to agriculture, the first metallurgy, weaving and crude pottery, which took place because of the existence of the city. These innovations, he argues, as well as every major innovation in human society come from cooperation, synergy, and multiple savings obtained from living in dense urban settlements. The externalities of cities and the various types of agglomeration economies (external, scale, scope, location, urbanisation) stem, on the one hand, from savings in energy, time and materials, and on the other hand, from collaboration and the creation of synergies. The spatial agglomeration of people and activities produces both savings and synergies.

The new industrial geography has described how proximity generates additional externalities in the innovation economy because of informal collaboration, untraded interdependences, knowledge spillovers, trust, and diffusion of tacit knowledge. It is the diversity of cities, the connected variety of the urban agglomeration that increases individual intelligence by bridging fields of knowledge. 'Related variety' (Boschma and Frenken, 2011) has been an influential concept in innovation-led regional development over 20 years, sustained by studies on innovative industrial districts containing many and diverse skills, on high technology regions with a variety of machinery and knowledge infrastructure, and on innovative cities with a variety of science and technology fields in world class research institutes and universities. The industrial innovation literature uses also similar 'brokering' concepts to explain how innovation derives from connecting various fields of research and technology and insights from connecting different fields of science and technology (Hargadon, 2003).

When digital applications begin to appear over the urban environment, collaboration and synergies scale-up. As citizens come into the digital space and use applications, they share more and share it quicker. Interaction becomes easier and synergy stronger. The holy triad of synergies (proximity, trust, communication) is strengthened: proximity increases because the 'other' is just a few clicks away; trust deepens because digital interaction leave traces; and communication intensifies because we have more means and tools to this end. Digital interaction enables wider collaboration, more extended supply chains, and more end-user participation. The agglomeration of digital applications and e-services, created by the engagement of the population of the city, scales-up collaboration with content management systems, co-design tools, collaborative work environments, crowdsourcing platforms, and content mash-ups.

As computers, devices, and information systems become embedded into cities, the collaboration patterns among citizens change substantially. Change does not concern scalability only, but above all the architectures of cooperation. New networking architectures emerge, involving both humans and machines. As digital technology transfers tasks from humans to machines, workflows become more complex, more tasks are performed in cooperation, machines inspect the workflow of collaboration, and storage capacity skyrockets. The city ends up with quicker responses, better quality procedures, lower operation costs, higher problem-solving capability; in other words, with higher spatial intelligence. This happens because machine intelligence is added to the human intelligence of citizens and to the collective intelligence of the community. The agglomeration of digital applications is the beginning of spatial intelligence in smart cities, in the same way that the spatial agglomeration was the beginning of cities.

(ii) Orchestration intelligence: Bletchley Park, the first intelligent community ever

The first community that successfully practised this type of human-machine cooperation and integration of individual, collective, and machine intelligence was Bletchley Park in the UK. The story of Bletchley Park is well known in the WWII code-breaking literature. However, it was never referred as an intelligent city or intelligent community.

Bletchley Park is located eighty kilometres north-west of London. Bletchley is an ordinary town, a regional urban centre in the county of Buckinghamshire, at the intersection of London and North-Western Railway with a line linking Oxford to Cambridge. Just off the junction, within walking distance from the station, lies Bletchley Park, an estate of about 100 hectares with a grand Victorian mansion at the centre of the estate.



The development of Bletchley Park started in August 1939 when the Government Code and Cypher School moved from London to Bletchley Park to carry out their code-breaking work in a safer environment. A small group of people was initially settled at Bletchley composed of code-breaking experts, cryptanalytic personnel, and university professors from the exact sciences and mathematics. Alan Turing arrived at Bletchley Park in 1939 together with other professors from Cambridge to help set up the methods of analysis and workflow of cryptanalysis. Bletchley Park carries the mark of A. Turing and his ideas on intelligence, logic and software priority over hardware, and solutions over a universal computing process.

The mission of Bletchley Park was to find the daily settings of the Enigma machines used by the German Army to encode all transmitted messages between the army headquarters, divisions, warships, submarines, port and railway stations, military installations and other installations, and then decode all these messages. It is estimated that by 1942 the German Army had a least a hundred thousand Enigma machines, which produced an enormous traffic of codified messages of vital importance for the daily operation of all army units. The Enigma machine was an electro-mechanical device for encryption and decryption of messages based on polyalphabetic substitution. It relied on interchangeable rotors of 26 letters, initially three and later five, moving rings, and a plugboard which permitted variable electrical wiring connecting letters in pairs. Every key pressed on the keyboard caused one step on the first rotor - after a full rotation the other rotors also moved - and then electrical connections were made that changed the substitution alphabet used for encryption. Decoding was symmetrical. The receiver had to settle the machine in its initial setting of rotors, rings, and plugging, type the coded message and recover the original. The combination of rotor order, the initial position of rotors, and plug settings, created a very large number of possible permutations. For each setting of rotors there were trillions of ways to connect ten pairs of letters on the plugboard. It was practically impossible to break the encryption by hand.

The Park was an 'industry' for information collection, processing, decoding, and distribution. Thousand messages were intercepted daily, while overall 200,000 – 500,000 German messages were decoded between 1940 and 1945. The impact was also extremely high. The strategic role of Bletchley Park was in the battle for supplies, defeating the U-boats in the Atlantic and securing the inflow of materials, foods and ammunition to Britain. By the end of 1941 the British announced that the problem of maritime supplies had been solved. Historians estimate that the work done in Bletchley Park shortened the war by two to four years and saved millions of lives. The philosopher George Steiner described Bletchley Park as the greatest achievement of Britain during the war and perhaps during the whole 20th century.

The amount of collaborative knowledge work carried out was enormous. That is important for Bletchley as an intelligent community. The work in Bletchley was done in wooden huts, designated by numbers, and brick-built blocks that were constructed after 1939 to house the different sectors of cryptanalysis. In the years thereafter, the personnel of Bletchley Park increased in number at a spectacular rate and by the end of the war they numbered about ten thousand. People came from all fighting services, and were seconded to Bletchley Park because of their skills; authors, diplomats, bankers, journalists, and teachers, and many women who received training in information processing tasks.

The workflow at Bletchley Park in breaking German communications codes was based on a collaborative schedule between scientists, experts, trained workers, and machines that offered increased intelligence to deal with this challenge. The methodological solutions about how to break the Enigma

ciphers were given by a group of British cryptanalysts and mathematicians at Bletchley Park who continued and enriched the methods devised by Polish mathematicians in previous and simpler models of Enigma machines. The wiring structure of the machines and some fundamental design flaws -no letter could ever be encrypted as itself- were exploited. The breaking of the codes was based on human factors and mistakes made by the Germans. Alan Turing and Cambridge mathematician Gordon Welchman, who also invented the method of perforated sheets, provided the designs for the new machine -the British Bombe- that could break any Enigma cipher, provided an accurate assumption could be made of about twenty letters in the message. Alan Turing contributed with several insights to breaking the Enigma cipher, while also somehow continuing his theoretical work on computable numbers and the Turing universal machine.

The key to the success of Bletchley Park was large-scale collaboration and an organised workflow that integrated a variety of information sources and processes. Cryptanalysts worked as a team. They had to analyse all the messages of the day to make assumptions out the basic setting of the rotors. Codebooks found in sunken submarines or captured ships were also very helpful and provided Enigma ground settings and abbreviations. They had to simulate the entire German classification system, mapping, and acronyms. Cryptanalysis acquired meaning only through the coordination of different activities across an extended workflow, and solving ciphers was only part of it. There was an organised division of labour and specialisation for different tasks along the process of intercepting the messages, transferring them to Bletchley Park, code breaking, verification, and dissemination of the information to recipients. The raw material came from a web of wireless intercept stations around Britain and overseas. Code-breakers based in the huts were supported by teams who turned the deciphered messages into intelligence reports. The letter from Turing, Welchman, Alexander and Milner-Barry to Churchill in October 1941, asking for more resources at Bletchley Park, personnel, night shifts, interception stations, specialised decoders, support to the Bombes, shows this integrated large-scale functioning of the community.

When a cryptanalyst developed an assumption about a possible way of breaking the code in a message, he prepared a menu (called a crib -plain text that corresponded to the cipher text) which was sent to be tested on a 'Bombe' machine. This was an electromechanical machine used to discover the set of rotors, the settings of the alphabet rings, and the wiring of the plugboard. The machine would check a million permutations, exclude those containing contradictions, and finally reveal how the Enigma machine had been set in order to produce this crib. The 'Bombe' would then provide a solution by discounting every incorrect one in turn. The first 'Bombe' was based on Turing's design and was installed at Bletchley Park in 1940. Subsequent versions were equipped with Welchman's diagonal board which could substantially decrease the number of possible rotor settings. In 1944 Colossus, the first digital electronic computer, became operational at Bletchley Park. Colossus was designed to break messages coded on Lorenz machines. The Lorenz machine created more complex ciphers using a code in which each letter of the alphabet was represented by a series of five electrical impulses. Obscuring letters were also generated by Lorenz's 12 rotors. The first Colossus arrived at Bletchley Park in December 1943. In practical terms Bletchley Park used the world's first electronic computer and digital information processing machine.

Bletchley Park had all the four essential characteristics that we now attribute to intelligent cities: (1) a creative population working in information and knowledge-intensive activities; (2) institutions and routines for collaboration in knowledge creation and sharing; (3) technological infrastructure for communication, data processing and information analysis; and (4) a proven ability to innovate and solve problems that appear for the first time. Bletchley Park was the first intelligent community ever



created.

Bletchley Park, as a prototype of an intelligent community, was an urban ecosystem in which the organised division of labour and the orchestration of distributed tasks based on institutional rules with the support of intelligent machines produced radical innovations. The military organisation in this district and the absence of the spontaneous complexity we usually find in cities, should not lead us to undervalue the innovativeness of its design and its effectiveness in dealing with extremely complex problems. It represents a top-down solution that was feasible under extreme conditions when the social division of labour within cities becomes a technical division also.

(iii) Empowerment intelligence: Cyberport Hong Kong up-skilling platforms

There are, however, other routes to spatial intelligence, which stand on the contribution of city districts and urban infrastructure to knowledge and skills development.

The spatial structure of intelligent cities is actually taking the form of 'knowledge ecosystems' and 'innovative districts' over 'smart networks'. This form is produced by the decentralisation of urban management and the development of smart urban networks. The literature on the clustering of innovation has explained the causes of spatial gathering and the creation of islands of innovation (Morgan, 2004; Simmie, 1998). Many types of clusters, such as cohesion clusters, industrial districts, innovative milieu, planned technology parks (Hart, 2000) with different sizes, activities, degrees of internal association, and input-output relationships operate over urban infrastructures. City networks for mobility, energy and utilities, on the other hand, are becoming smarter in the pursuit of environmental sustainability and resource savings. It is estimated that smart infrastructure, smart grids, sensors, wireless meters, and actuators, might have a higher impact on energy savings and CO₂ reduction than the total positive effect from renewable energy sources.

Metropolitan strategic plans like the "Melbourne 2030 Plan" and Stockholm's "Vision 2030" have clearly adopted this strategy of organising innovation ecosystems and knowledge-intensive districts over advanced infrastructure, including broadband, telecommunications, energy, smart transport and logistics. Melbourne has institutionalised this district-led development via "knowledge precincts", areas surrounding university campuses in which special land use regulations favour the location of activities that link to university infrastructure and R&D, offering opportunities for technology diffusion and cross fertilisation between high-tech businesses, academia, and public facilities (Yigitcanlar et al., 2008). This architecture is beneficial for all innovation ecosystems of a city, which profit from technology networking, knowledge spillovers, and knowledge transfer.

Moreover, some urban ecosystems are pursuing conscious strategies for involving the wider population of the city, not just producers and technologists, and are creating large-scale up-skilling with education and learning on experimental facilities and ICT infrastructure. Living Labs, for instance, offer a good case of user involvement and large-scale creativity development. Users take part in new product development and testing within real urban environments and participatory innovation processes integrating co-creation activities, bringing together technology push and application pull, exploration activities engaging user communities in an earlier stage of the co-creation process, experimentation activities, implementing the proper level of technological artefacts to experience live scenarios, and evaluation of new ideas and innovative concepts and technological artefacts in real life situations (Pallot, 2009). Such open and user-centric innovation ecosystems operate in many and diverse sectors, such as mobile communications, media, agriculture, food industry, health, medicine,

e-government services, smart cities, sports, education, and social work.

There are also city ecosystems that act as 'innovation universities' or 'intelligent campuses', which use the built environment of the city and experimental facilities to disseminate learning and innovation. Large-scale up-skilling strategies thus become possible; thereby improving the creativity, intelligence and inventiveness of the population, and introducing 'innovation-for-all' environments, in which every citizen or company can become a producer of services and active innovator.

Cyberport Hong Kong is an innovation ecosystem that has effectively advanced this strategy of up-skilling, using advanced telecommunication infrastructure and multimedia technologies organised into knowledge district. Cyberport is a new district located on the west side of Aberdeen Country Park on Hong Kong Island. The district has been developed as a government programme aimed at developing the knowledge economy of Hong Kong. As an autonomous technology district, Cyberport is focusing on professional and enterprise development, offering an open platform for innovative ideas to flourish and for start-ups in the field of media technologies. The district is wholly owned by the Hong Kong SAR Government and managed by Cyberport Management Company Limited.

Cyberport includes many different activities, land uses, and zones. Within a relatively small piece of land of 24 hectares there is an enterprise zone with four quality buildings that host about 100 information technology and media companies, a research institute, business incubator, conference centre, shopping mall, 5-star Le Meridien hotel, a huge housing complex, and a large park at the heart of Cyberport which extends along the coastline. The area is served by fibre optic and copper networks offering high speed broadband connections and a wide range of digital services and laboratory equipment. Buildings in the technology zone are grade-A intelligent office buildings. All these activities are organised into four different zones: the technology zone with Cyberport 1, 2, 3, and 4 buildings; the commercial zone with the mall and the hotel; the residential zone; and the park and open green area zone. Despite this functional division, the relatively small surface of the district and the openness here create a continuum of uses as all the spaces are accessible to the community of the district.

Activities and land uses have been selected to promote the mission of the district and ensure its sustainability. Cyberport was developed on public land and the construction work took place from 2000 to 2008. The funding scheme foresaw a split into two parts, the Cyberport zone and the ancillary residential zone. The mission of the Cyberport zone was to create a strategic cluster of leading information technology and information services companies and a critical mass of professionals in these sectors. The mission of the residential zone was to generate revenue for the Cyberport project. A development company acquired part of the land (about 20% of the plot) together with the infrastructure already on site to build the residential zone. The developer (Cyber-Port Limited) was responsible for the total construction costs of both the Cyberport and the housing complex (Hong King Legislative Council, 2002). The residential zone includes eight 50-storey high buildings and two lower complexes - two to five storeys - for high income residences along the coast. Overall 2,800 homes were built. In return for the concession of the land and infrastructure of the residential zone, the developer delivered the technology zone as a turn-key solution, with Cyberport 1, 2, 3, and 4, the shopping mall arcade, the 5-star hotel operated by Le Meridien, and the central park. Revenues generated by the commercial zone -mall and hotel- go to the technology zone and cover training, learning, and incubation expenses. The district was publicly funded and serves the public interest. This genuine funding model contributes both to development and operation of Cyberport 1, 2, 3, 4, and to the public and open character of the district.



Cyberport should not be seen as usual technology district or a technology park. It is a community that nurtures talent in the media industry, turning skills and talent into start-ups. It amplifies the skills and creativities of the Hong Kong population using experimental digital infrastructure and open platforms. The objectives are technology diffusion, up-skilling, and the enhancement of human capabilities. Cyberport is a creative community supplied with advanced communication and media infrastructure and digital connectivity. "Cyberport identifies, nurtures, attracts and sustains talent so it is able mobilise ideas, talents and creative organisations. It is a creative milieu; a place that contains the necessary requirements in terms of hard and soft infrastructure to generate a flow of ideas and inventions" (Interview with CEO of Cyberport N. Yang). The focus of the district is the IT and multi-media sector, where it sustains a creative community. Technologies and digital applications that have been developed in Hong Kong Universities or the Technology Park can be transferred to the younger generation through practical learning and experimental training. Training from the world's leading media and IT companies is provided together with the laboratory equipment and start-up funding for follow-up training that promotes entrepreneurship.

To achieve these objectives Cyberport has developed state-of-the-art infrastructure, media equipment and digital services which are organised as open technology learning platforms. Each platform serves a specific objective of training, creativity, and entrepreneurship.

- The Digital Entertainment Incubation and Training Programme is a platform whose objective is to build and promote entrepreneurship and competence in the digital entertainment industry, focusing on business skills, games, animation and digital entertainment, and to enhance networking with industry, as well as to promote the awareness and interest of the younger generation in digital entertainment.
- The Digital Media Centre is a unique state-of-the-art digital multimedia creation facility, whose objective is to offer software and hardware support to content developers, multimedia professionals, small- and medium-sized enterprises.
- The iResource Centre is a digital content storage platform, which serves as a trusted marketplace and clearing house for the aggregation, protection, license issuance and distribution of digital content.
- The Testing and Certification of Wireless Communication Platform provides continuous mobile communication services and coverage of mobile phone signals (3G, GSM, CDMA and PCS) in both outdoor and indoor areas within Cyberport in cooperation with major mobile communications service operators.
- The Cyberport Institute was established by the University of Hong Kong to introduce and run IT courses for talented people and to support various IT development and related businesses in Hong Kong.

These open technology platforms are operated in cooperation with industry leaders who are the founding industrial partners. CISCO, Hewlett Packard, IBM, Microsoft, Oracle and PCCW have been involved through sponsorship programmes, while the students benefit from access to top-of-the-market technologies, scholarships, placement opportunities, and employment.

The dual mechanism described above entailing (1) the open digital technology platforms, and (2) the real-estate based sustainability, provides an open-ended mechanism for professional training, learning, and up-skilling (Fig. 1). The setting enhances human capabilities and intelligence by simultaneously providing hard urban infrastructure and soft digital technologies and services. Developed on public land, Cyberport is creating intelligence through up-skilling funded by real estate business models, and spreading out skills and capabilities into the entire urban system of Hong Kong.

- (iv) Instrumentation intelligence: Amsterdam and Santander smart metering projects for envi-

ronmental sustainability

Among the most influential contributions to the creation of city intelligence has been the IBM Smart Planet - Smarter Cities initiative based on the combination of broadband networks, smart meters, and predictive modelling. City intelligence is improved by making the city systems 'interconnected' and 'instrumented' and by using the information gathered to identify patterns of behaviour, develop predictive models of likely outcomes, and more informed decision-making (Dirks and Keeling 2009; IBM, 2010). It is estimated that this instrumentation intelligence might offer significant savings in city traffic, energy, health, and public safety costs (Kaiserswerth, 2010). IBM is testing this concept through partnerships with cities worldwide. In many cities, the company and local administrations work together to provide this type of solutions in energy, water management, and transportation, reducing the city's footprint on the environment.

This concept of spatial intelligence is clearly applied in the experimental facility of Smart Santander in the city of Santander, in northern Spain. The facility, funded by FP7, has installed a city-wide network of sensors and devices to monitor pollution, noise, traffic and parking. The test bed is composed of around 3,000 IEEE 802.15.4 devices, 200 GPRS modules and 2,000 joint RFID tag/QR code labels deployed over the built environment of the city and moving vehicles, buses and taxis. A long term plan envisions the deployment of about 20,000 sensors. Devices work over a common IP infrastructure using cellular, radio meshed networks, and available broadband (Krcro, 2010). The architecture supports a secure and open platform of heterogeneous technologies and the facility applies user-driven innovation methods (through competitive open calls) for the design of innovative applications and implements 'use cases', such as bus tracking, air quality monitoring, urban waste management, and others. The facility is open to researchers and service providers to test architectures, enabling technologies, and pilot applications, the interaction and management of protocols, and support services such as discovery, identity management and security, and the social acceptance of services related to the Internet of Things (Smart Santander). The OSWINDS Group, for instance, run the SEN2SOC experiment over Smart Santander, connecting sensor measurements and social network interactions and producing new user-oriented services which can test and improve the infrastructure itself (Vakali et al., 2013).

Instrumentation intelligence is also widely implemented in Amsterdam Smart City. Smart devices and wireless meters transmit information over broadband networks and provide intelligence to citizens and organisations of the city to optimise energy saving practices. Decisions can be made with respect to accurate and on time information provided by smart devices or by the crowd. Many solutions for this type of logic are being implemented in different districts of the city: housing and living (West Orange, Geuzenveld, Haarlem, Onze Energie), working (ITO Tower, monumental buildings, employee contest), mobility (Ship to Grid, Moet je Watt), and public space (Climate Street, smart schools, ZonSpot, smart swimming) (Baron, 2011). Overall 43 projects are being implemented in three areas (Ijburg, Nieuw West, Zuid Oost) and five themes (Living, Working, Mobility, Public Facilities, Open Data) (Amsterdam Smart City).

In the Haarlem area for instance, 250 users can test an energy management system and get insight into the energy consumption of appliances, enabling monitoring of energy usage and appliances to be remotely switched on and off. In the Geuzenveld neighbourhood, 500 homes have been provided with smart metres and energy displays to become aware of energy consumption and discuss energy savings at brainstorming sessions. In the West Orange project, 500 households have been provided with smart metres and displays and a personal energy saving goal is set for every household. The

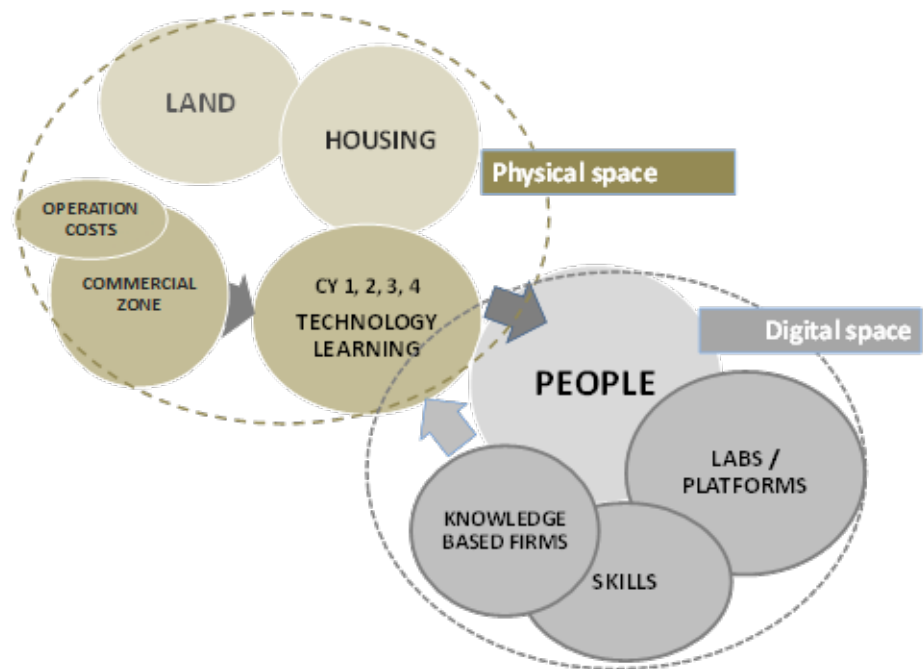


Figure 1.
Cyberport up-skilling
and empowerment
infrastructure and
circuits.

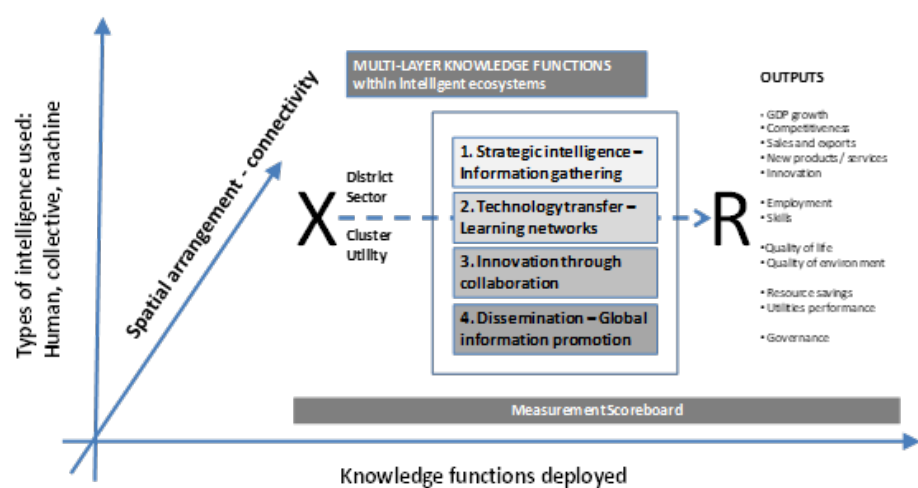


Figure 2.
Generic dimensions
of city intelligence

overall goal is to save at least 14% energy and reduce CO2 emissions by an equal amount. The ITO tower, a large multi-tenant office building, is testing which smart building technologies, cooperative agreements and practices can make office buildings more sustainable. Information gained by smart plugs and insight based on data analysis are used to provide more efficient solutions. In the Utrechtsestraat, a shopping street with numerous cafés and restaurants, 140 small enterprises are testing solutions for a more sustainable environment: logistics using electric vehicles, energy saving lamps for street lighting dimmed during quiet times, solar-powered garbage compactors, smart metres and displays for energy consumption, and incentives and benefits arising from energy savings (Amsterdam Smart City, 2009). The city also is experimenting with crowdsourcing, co-creation, open data, and open innovation to involve citizens in finding better solutions for public space and mobility. Ambitious goals were set to reduce CO2 emissions by 40% and achieve a 20% energy reduction in 2025 compared to a 1990 baseline. Key performance indicators show that these goals can be achieved. In the Climate Street already more than 50% sustainable waste collection and 10% energy savings have been recorded.

Towards a universal architecture of intelligence in smart cities

Moving beyond the baseline of agglomeration intelligence, orchestration, empowerment, and instrumentation intelligence show different architectures of connectivity between digital and non-digital entities, which cities adopt to increase their problem-solving capability. Spatial intelligence actualises arrays of knowledge functions and smart systems to more efficiently manage available city resources and human capital. They articulate large-scale and city-wide endowments of different types of intelligence, namely collective, human, and machine intelligence. All architectures of spatial intelligence increase the efficiency of cities to address complex and non-linear problems, but they do it in very different ways. They constitute different pathways to problem-solving and innovation.

A few variables, however, generate the above types of spatial intelligence:

- the knowledge functions involved, which might relate to information-in, information-out, learning, creation of new knowledge;
- the intelligence used, which might be primarily human, collective from collaboration, or machine intelligence relying on sensors, data, software, and self-control systems;
- the connectivity, workflow and arrays followed, which might entail different complementarities between the spatial, institutional, and digital dimensions of cities.

Orchestration is based on the large-scale division of work and integration of knowledge tasks which are distributed among the members of a community. Each task may be simple, but the size of the collaboration defines the complexity of the entire knowledge process. The overall result may be truly innovative. Empowerment rests on improvements of individual skills, capabilities, and know-how. It is an individual learning process, but when practiced massively on the entire city can produce great results. Instrumentation intelligence replicates computer processes at city level, gathering information from sensors, social media, and urban activities, processing this information, and providing real-time information, alerts, forecasts, and hopefully wiser decisions.

Clearly, orchestration, empowerment and instrumentation are not the only feasible forms of spatial intelligence produced from these variables. Evidently, many more combinations are possible. Future Internet technologies and future media research, for instance, are bringing in new solutions in terms physical – digital relationships, with new infrastructure (cloud computing, RFIDs, sensors, real world user interfaces, mobile devices), data (open data, linked data), and trusted services.



Such forms of spatial intelligence can be practiced in all domains of cities: the innovation economy of cities with the different city districts, sectors of economic activity, clusters and the ecosystems that they contain; the quality of life with e-services for social care, health, safety, environmental monitoring and alert; the utilities of cities with their different networks, flows and infrastructures for energy, transport, water and waste; and the governance of cities with services to citizens, decision-making procedures, participation and more direct democracy. At least twenty-five different domains of cities or ecosystems can be identified as potential fields for deploying spatial intelligence using hundreds of applications and e-services.

Thus, in each of city ecosystem (district, sector or network) spatial intelligence emerges from the combination of knowledge processes, the type of intelligence involved, and the type of spatial arrangement installed (Fig. 2). Outputs and effectiveness in terms of city growth, employment and environmental sustainability depend on how these variables are combined. It is a critical issue for smart city planning and governance to select the most effective combination of variables with respect to the character of the city and the problems in focus. Instrumentation, for instance, seems more suitable for providing resource efficient urban networks, and sustainable transport, energy, and environment; orchestration offers advantages in terms of quality of service and operation costs in well-structured areas such as ports and technology districts; empowerment is a good solution for innovative clusters, start-ups, employment generation, leading to more competitive places.

Intelligent cities are expected to and have promised more efficiently address contemporary urban challenges. However, to date intelligent city strategies seem to have a rather limited impact on the great challenges of cities concerning competitiveness, employment, and environmental sustainability. This mismatch signifies several things: that smart environments are not well targeted at city challenges; that solutions are more technology push than need driven; or that cities have not developed sufficient spatial intelligence. All explanations can be true, and cities with all the technology and institutions they actually have are not yet sufficiently intelligent. By and large, contemporary solutions are lagging in terms of radical innovation achievement (Kominos et al., 2016) and the social impact reached by Bletchley Park.

We have entered the age of intelligent cities, but we still lack a deeper understanding of the processes that create city intelligence. Most conceptualizations of intelligent / smart cities stress the use of information and communications technologies to make cities more innovative and efficient. But, they do not equally stress other dimensions of spatial intelligence and forms of integration among the digital space and open connected communities, innovation institutions and networks, regeneration strategies, measurement and assessment systems, decision-making capabilities, which generate the intelligence of cities. It is important to underline that city intelligence does not concern the digital space of cities only, but the connectivity and integration of digital solutions with city institutions and skills and competences of citizens (Kominos et al. 2014). In this sense, connected intelligence is concept that captures better the intelligence of cities. We should engineer solutions based on connected intelligence, adapted to every sector, district, and innovation ecosystem of a city, as integration and connectivity are keys to higher spatial intelligence, innovation and efficiency.

References

- Amsterdam Smart City (2009). Introduction Amsterdam Smart City. Amsterdam: Municipality of Amsterdam.
- Amsterdam Smart City. Projects. Retrieved, 2 January 2014, from <<http://amsterdamsmartcity.com/projects>>.
- Angelidou, M. (2015). Smart cities: A conjuncture of four forces. *Cities*, 47, 95-106.
- Antirroiko, A.V. (2005). *Cybercity*. Encyclopedia of the city. London: Routledge.
- Baron, G. (2011). *Amsterdam smart city*. Amsterdam: Amsterdam Innovation Motor.
- Bell, R., Jung, J., and Zacharilla, L. (2009). *Broadband economies: Creating the community of the 21st century*. New York: Intelligent Community Forum Publications.
- Belissent, J. (2010). Getting clever about smart cities: New opportunities require new business models. Forrester for Ventor Strategy Professionals. Retrieved, 2 January 2014, from <<http://goo.gl/hnuuRo>>.
- Bergvall-Kåreborn, B. and Ståhlbröst, A. (2009). Living Lab: An open and citizen-centric approach for innovation. *International Journal of Innovation and Regional Development*, Vol. 1 No. 4, 356-370.
- Boschma, R., and Frenken, K. (2011). Technological relatedness and regional branching. In H. Bathelt, M.P. Feldman, and D.F. Kogler (eds.), *Beyond territory: Dynamic geographies of knowledge creation, diffusion, and innovation* (pp. 64-81). London: Routledge.
- Caragliu, A., Del Bo, C. and Nijkamp, P. (2009). *Smart cities in Europe*. Amsterdam: VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics.
- Chen-Ritzo, C.H, Harrison, C., Paraszczak, J., and Parr, F. (2009). Instrumenting the planet. *IBM Journal of Research and Development*, Vol. 53.3, 338-353.
- Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., ... & Scholl, H. J. (2012, January). Understanding smart cities: An integrative framework. In *System Science (HICSS), 2012 45th Hawaii International Conference on* (pp. 2289-2297). IEEE.
- Couclelis, H. (2004). The construction of the digital city. *Environment and Planning B: Planning and Design*, Vol. 31, 5-19.
- Deakin, M. and Allwinkle, S. (2007). Urban regeneration and sustainable communities: the role networks, innovation and creativity in building successful partnerships. *Journal of Urban Technology*, 14(1), 77-91.
- Deakin, M. (2011). The embedded intelligence of smart cities. *Intelligent Buildings International*, Vol. 3.3, 189-197.
- Dirks, S. and Keeling, M. (2009). *A vision of smarter cities*. Dublin: Centre for Economic Development, Ireland.
- Graham, S. (ed.) (2003). *The cybercities reader*. London: Routledge.
- Graham, S. (2010). *Cities under siege: The new military urbanism*. London: Verso Books.



- Hargadon, A. (2003). *How breakthroughs happen. The surprising truth about how companies innovate*, Boston MA: Harvard Business School Press.
- Hart, D.A. (2000). *Innovation clusters: Key concepts*. Working paper, Department of Land Management and Development, and School of Planning Studies, The University of Reading, United Kingdom.
- Hiramatsu, K., and Ishida, T. (2001). *An augmented web space for digital cities. Applications and the Internet 2001 Proceedings*. Retrieved, 2 January 2014, from <http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=905173>.
- Hong Kong Legislative Council (2002). *Background brief on Cyberport*. Legislative Council Secretariat. Retrieved, 2 January 2014, from <<http://www.legco.gov.hk/yr01-02/english/panels/itb/papers/itb0708cbl-2172-1e.pdf>>.
- IBM (2010). *A vision of smarter cities: How cities can lead the way into a prosperous and sustainable future*. IBM Global Services.
- Ishida T., and Isbister K. (eds) (2000). *Digital cities: Technologies, experiences, and future perspectives*. Berlin: Springer-Verlag.
- Jacobs, J. (1969). *The economy of cities*. New York: Random House.
- Kaiserswerth, M. (2010). *Creating a smarter planet: One collaboration at a time*. IBM Research Zurich. Retrieved, 2 January 2014, from <http://www.earto.eu/fileadmin/content/01_Seminars_Conferences/AC_2010/4-Matthias_Kaiserswerth.pdf>.
- Kakderi, C., Komninos, N., & Tsarchopoulos, P. (2016). *Smart cities and cloud computing: lessons from the STORM CLOUDS experiment*. *Journal of Smart Cities*, 2(1), 4-13.
- Komninos N. (2002). *Intelligent cities: Innovation, knowledge systems, and digital spaces*. London: Routledge.
- Komninos, N. (2006). *The Architecture of Intelligent Cities*. *Intelligent Environments 06*. 2nd IET International Conference Proceedings, (pp 53-61). Institution of Engineering and Technology.
- Komninos N. (2008). *Intelligent cities and globalisation of innovation networks*. London and New York: Routledge.
- Komninos, N. (2014). *The Age of Intelligent Cities. Smart Environments and Innovation-for-all Strategies*, Routledge: London and New York,
- Komninos, N., Tsarchopoulos, P., & Kakderi, C. (2014, August). *New services design for smart cities: A planning roadmap for user-driven innovation*. In *Proceedings of the 2014 ACM international workshop on Wireless and mobile technologies for smart cities* (pp. 29-38). ACM.
- Komninos, N., Bratsas, C., Kakderi, C., & Tsarchopoulos, P. (2016). *Smart city ontologies: Improving the effectiveness of smart city applications*. *Journal of Smart Cities*, 1(1), 31-46.
- Krco, S. (2010). *SmartSantander - A smart city example*. ICT event 2010. Brussels: Belgium, 27-29 September.
- Mitchell, W. (1996). *City of Bits: space, place and the infobahn*. Cambridge, MA: Massachusetts Institute of Technology.

- Mitchell, W. (2007). Intelligent cities. E-Journal on the Knowledge Society, UOC Papers. Retrieved, 2 January 2014, from < <http://www.uoc.edu/uocpapers/5/dt/eng/mitchell.html>>.
- Morgan, K. (2004). The exaggerated death of geography: Localised learning, innovation and uneven development. *Journal of Economic Geography*, Vol. 4.1, 3-21.
- Pallot, M. (2009). Engaging users into research and innovation: The living lab approach as a user centred open innovation ecosystem. Retrieved, 2 January 2014, from Webergence Blog. <http://www.cwe-projects.eu/pub/bscw.cgi/1760838?id=715404_1760838>.
- Schaffers, H., Komninos, N., Pallot, M., Trousse, B., Nilsson M., and Oliveira, A. (2011). Smart cities and the future Internet: Towards cooperation frameworks for open innovation. *The Future Internet*, Lecture Notes in Computer Science, Vol. 6656, 431-446.
- Segaran, T. (2007). Programming collective intelligence: building smart web 2.0 applications. O'Reilly Media, Inc.
- Shiode, N. (1997). An outlook for urban planning in cyberspace: Toward the construction of cyber cities with the application of unique characteristics of cyberspace. *Online Planning Journal*, Oct. Nov. Retrieved, 2 January 2014, from <<http://www.casa.ucl.ac.uk/planning/articles2/urban.htm>>.
- Simmie, J. M. (1998). Reasons for the development of 'Islands of innovation'. Evidence from Hertfordshire'. *Urban Studies*, 35 (8), 1261-1289.
- Smart Santander. SmartSantander Experimental Test Facilities. Retrieved, 2 January 2014, from <<http://www.smartsantander.eu/index.php/testbeds>>.
- Soja, E. (2003). Writing the city spatially. *City*, Vol. 7.3, 269-280.
- Tsarchopoulos, P., Komninos, N., & Kakderi, C. (2017). Accelerating the uptake of smart city applications through cloud computing. *World Academy of Science, Engineering and Technology, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, 11 (1), 129-138.
- Vakali, A., Angelis, E. and Giatsoglou, M. (2013). Sensors talk and humans sense towards a reciprocal collective awareness smart city framework. *IEEE International Conference on Communications (IEEE ICC)*. Retrieved, 2 January 2014, from <<http://smartsantander.eu/index.php/sen2soc>>.
- Van den Besselaar, P., and Koizumi, S. (2005). Digital cities III. Information technologies for social capital: Cross-cultural perspectives. Amsterdam and Berlin: Springer-Verlag.
- Yigitcanlar, T., O'Connor, K. and Westerman, C. (2008). The making of knowledge cities: Melbourne's knowledge-based urban development experience. *Cities*, Vol. 25.2, 63-72.
- Yovanof, G. S., and Hazapis, G.N. (2009). An architectural framework and enabling wireless technologies for digital cities & intelligent urban environments. *Wireless Personal Communications*, Vol. 49.3, 445-463.



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Machine Learning as enabler of Design -to-Robotic -Operation

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Abstract

This essay promotes Artificial Intelligence (AI) via Machine Learning (ML) as a fundamental enabler of technically intelligent built-environments. It does this by detailing ML's successful application within three deployment domains: (1) Human Activity Recognition, (2) Object as well as Facial-Identity and -Expression Recognition, and (3) Speech and Voice-Command Recognition. With respect to the first, the essay details previously developed ML mechanisms implemented via Support Vector Machine and k-Nearest Neighbor classifiers capable of recognizing a variety of physical human activities, which enables the built-environment to engage with the occupant(s) in a highly informed manner. With respect to the second, it details three previously developed ML mechanisms implemented individually via (i) BerryNet—for Object Recognition; (ii) TensorFlow—for Facial-Identity Recognition; and (3) Cloud Vision API—for Facial-Expression Recognition; all of which enable the built-environment to identify and to differentiate between non-human and human objects as well as to ascertain the latter's corresponding identities and possible mood-states. Finally, and with respect to the third, it details a presently developed ML mechanism implemented via Cloud Speech-to-Text that enables the transcription of spoken speech—in several languages—into string text used to trigger pertinent events within the built-environment. The sophistication of said ML mechanisms collectively imbues the intelligent built-environment with a continuously and dynamically adaptive character that is central to Design-to-Robotic-Operation (D2RO), which is the Architecture-informed and Information and Communication Technologies (ICTs)-based component of a Design-to-Robotic-Production & -Operation (D2RP&O) framework that represents an alternative to existing intelligent built-environment paradigms.

Keywords

Design-to-Robotic-Operation, Machine Learning, Human Activity Recognition, Computer Vision, Voice Recognition

Introduction

Intelligence in the built-environment as a discourse began in the late 60s and early 70s (Cook, 1970, 1972; Eastman, 1972; Negroponte, 1969, 1975; Pask, 1975a, 1975b). Due to the rudimentary state and forbidding costs of Information and Communication Technologies (ICTs) during this period, explorations were principally limited to theoretical and/or hypothetical. But over the next two decades, and driven by increasingly sophisticated and accessible ICTs, explorations gradually produced physical implementations. From said nascent period throughout early physical implementations, two main emphases emerged within the same discourse: one centered around the technical context and the other around the architectural.

With respect to the technical, Ambient Intelligence (Aml) was coined in the late 90s to describe a vision of a future digital living room, a built-environment whose ICTs imbued its dwelling space with serviceable intelligence to the benefit of its occupant(s) (Zelkha et al., 1998). Within Aml a further specialized domain developed, i.e., that of Ambient Assisted Living—or Active and Assisted Living—(AAL), which framed its inquiry around the promotion of quality of life as well as the prolongation of independence with respect to Activities of Daily Living (ADLs) among the elderly via technical assistance. By the first decade of the 21st century, Aml and AAL were established and proliferating topics within the fields of Computer Science and related Engineerings (Lindgren et al., 2016; Paz Santana et al., 2017), Architectural Engineering (Bock et al., 2015; Georgoulas et al., 2014), and—in directly—in the Medical Sciences (Acampora et al., 2013).

With respect to the architectural, and beginning with Cedric Price's pioneering Generator Project and corresponding programs by John and Julia Frazer (Stenson, 2014) in the late 70s, notions of interaction between non-human and human agents in the built-environment began to be envisioned. For example, in Price's project, architecture was conceived as a set of interchangeable subsystems integrated into a unifying computer system, which enabled a reconfigurability sensitive to function. More importantly, both Price and the Frazers intended for the system itself to suggest its own reconfigurations, denoting non-human agency in the built-environment. Although the Generator Project was never realized, it became the de facto first instance of a subset field in Architecture concerned with bi-directional communication and interaction between non-human and human agents in the built-environment, viz., Interactive Architecture (IA) (Fox, 2010; Oosterhuis, 2012) first and Adaptive Architecture (AA) (Jaskiewicz, 2013; Kolarevic, 2014) later, which—like Aml—have also proliferated in the 21st century.

The proliferation of intelligence in the built-environment with respect to Aml/AAL surpasses that of IA/AA in terms of technical complexity, reliability, and performance. This is due to their differing emphases, with the technical focusing on ICTs and corresponding services and the architectural on spatial experience, materiality, function, and form. That is, the technical proliferated alongside sustained development of ICTs over decades in ways that the architectural could not, at least not with the same affinity and immediacy. Nevertheless, technical sophistication or lack thereof alone has not necessarily guaranteed or disqualified contributions in the discourse. Indeed, principally technical as well as principally architectural explorations have both independently identified key effective as well as affective desiderata common to built-environments—intelligent or otherwise—construed as successful with respect to function as well as to spatial experience. This consideration includes a caveat: while both the technical as well as the architectural have yielded independent contributions, these have been otherwise limited by the lack of mutually provided input and/or feedback. However, the promise of solutions yielded by both principally technical Aml/AAL and principally architectural



IA/AA explorations have been unwittingly and invariably limited by the rigid and increasingly outdated character of their complementing frameworks. This is because the sophistication of a system depends on that of its mutually complementing subsystems; and two or more subsystems may not mutually complement, sustain, and/or support one another adequately if their levels of development and sophistication do not correspond (Milgrom, 1990). More succinctly expressed: at present, the architectural does not correspond to the technically superior Aml/AAL, while the technical does not correspond to the architecturally superior IA/AA. Consequently, a different design paradigm / framework is required in order to enable comprehensively and cohesively intelligent built-environments with corresponding levels of technical and architectural sophistication.

The work detailed in this essay belongs to the Design-to-Robotic-Operation (D2RO) component of the Design-to-Robotic-Production & -Operation (D2RP&O) framework. D2RP&O considers the technical as well as the architectural in conjunction from the early stages of the design and development processes, where the built-environment is construed as a highly sophisticated and integrated Cyber-Physical System (CPS) (Rajkumar et al., 2010) consisting of mutually informing computational and physical mechanisms that operate cooperatively and continuously via a highly heterogeneous, partially meshed, and self-healing Wireless Sensor and Actuator Network (WSAN) (Yang, 2014). Via a series of limited and progressively complex proof-of-concept implementations (Liu Cheng, 2016; Liu Cheng et al., 2018; Liu Cheng and Bier, 2016a, 2016b, 2018; Liu Cheng, Bier, Latorre et al., 2017; Liu Cheng, Bier, Mostafavi, 2017), the feasibility and promise of D2RP&O in general and D2RPO in particular have been demonstrated. In this essay, two previously and one presently developed core Machine Learning (ML) mechanisms are detailed in order to assert the promise of Artificial Intelligence (AI) as a fundamental enabler of intelligent built-environments: (I) ML and Human Activity Recognition (HAR), (II) ML and Object as well as Facial-Identity and -Expression Recognition, and (III) ML and Speech and Voice-Command Recognition. These mechanisms are part of a prescriptive System Architecture intended to serve as the technical backbone of highly sophisticated (i.e., artificially intelligent, intuitively adaptable, and continuously evolving, etc.) intelligent built-environments.

Machine Learning and Human Activity Recognition

HAR enhances the built-environment's ability to respond adequately to the daily habits of the occupant(s). It enables said environment to build an accurate activity profile that informs proactive intervention routines intended to promote well-being. For example, via HAR a built-environment may prompt the occupant(s) to engage in physical activity when prolonged periods of inactivity have been detected. Furthermore, ventilation systems may be engaged whenever HAR and temperature / humidity sensors integrated in the built-environment detect an increase of interior temperature correlated with high physical activity. As with all other mechanisms within the System Architecture, HAR increases the resolution of the information that the built-environment receives as sensed input, which is directly correlated with the quality and pertinence of the actuated output.

In this section, previously developed (see Liu Cheng, Bier, Latorre et al., 2017) HAR mechanisms are detailed. These mechanisms integrate both cloud-based as well as localized ML capabilities in order to ascertain robustness and resilience. Whenever possible, ML processes are locally and dynamically executed via ad hoc node-clustering. But should this prove impossible either due to failure or unavailability of adequate resources, cloud-based ML services are used. More specifically, two ML mechanisms are integrated into the prescribed System Architecture: (1) a localized ad hoc cluster system based on open-source and purpose-written Python scripts, and (2) a simulated cloud-based analytics service using MathWorks® MATLAB™. Both mechanisms in this system use accelerometer data streamed from a smartphone and each uses polynomial programming of Support Vector

Machine (SVM) and k-Nearest Neighbor (k-NN) classifiers.

Due to their evolving and resilient characters, ML classifiers have been implemented in a variety of applications built on WSANs (Alsheikh et al., 2014). HAR, as one such application, has successfully exploited said classifiers in the last five years (see, for example, Andreu and Angelov, 2013; Villa, 2012; Xiao and Lu, 2015). However, due to the cost-effective and low energy-consumption character typical of WSAN nodes, computational processing with respect to feature extraction has been considerably limited (Salomons et al., 2016). The implementation in question overcomes this limitation by instantiating ad hoc clusters consisting of a variety of high-performance nodes. Furthermore, several clusters may be instantiated simultaneously in order to enable parallel high-performance information processing activities. The system's clustering mechanism uses the Message Passing Interface (MPI) standard via MPI for Python (mpi4py) (Dalcin et al., 2011). Another way to overcome this limitation—and one also implemented—is to avoid it altogether by outsourcing all high-performance information processing to cloud-based ML services. But there are a number of limitations with this approach. The first, and perhaps the most salient, is the cost incurred by including proprietary services in any proposed intelligent built-environment solution. A second yet no less important limitation may be the impact to the solution's resilience. That is to say, should said built-environment lose access to the Internet, it would be incapable of generating classification models.

In the local mechanism, a script based on pyOSC (V2_Lab, 2008) is first written to receive OSC data from any device and application capable of broadcasting in said protocol. While all the WiFi-enabled nodes in the system's WSAN have the capacity to receive this data-streaming, only one of the nodes of the cluster instantiated to generate classification models stores it locally and streams it to a cloud-based data visualization service. Should the receiving node fail, another high-performance node replaces it automatically. The proposed solution uses a smartphone (ML for HAR has typically used gyroscopic / accelerometer data collected via portable devices—see Anguita et al., 2013; Ortiz, 2015—or via sensor-fusion—see Palumbo et al., 2016), and the script in question proceeds to parse and to reduce the noise in the received data in order to generate a robust dataset. At this point the dataset is processed through two ML scripts based on scikit-learn (Buitinck et al., 2013; Pedregosa et al., 2017), one for SVM and another for k-NN classification models. In this particular implementation, the SVM model attained a 95.71% HAR prediction success rate and the k-NN model a 97.85%. The success rate attained by the local k-NN model was 2% higher than its counterpart model generated externally with MATLAB (i.e., 95.9%), while the local SVM model was 2% less successful than its MATLAB counterpart (see figure 1). This is a strong argument to prefer the open-source alternative.

Machine Learning and Object as well as Facial-Identity and -Expression Recognition

Computer Vision enables the built-environment to recognize the object and persons within it, which is a pertinent prerequisite for actuations that involve interaction with them. For example, if an object has collapsed within the built-environment, whether emergency intervention and notification protocols be initiated or not would depend on whether said object was a person or not. Object Recognition enables the built-environment to do this. Moreover, if the collapsed object has been detected to be a person, perhaps the identity and facial expression of the person would serve as indicators of the nature (e.g., intentional, accidental, etc.) of this fall. This is where Facial-Identity and -Expressions recognition plays a crucial role. These three Computer Vision features combined enable the built-environment so see its context and to corroborate phenomena as perceived by



Figure 2.
Left: Receiving
OSC-data; bottom:
95.71% prediction
success with respect
to HAR via SVM (left)
vs. 97.85% via k-NN
(right). Right: MAT-
LAB ML results

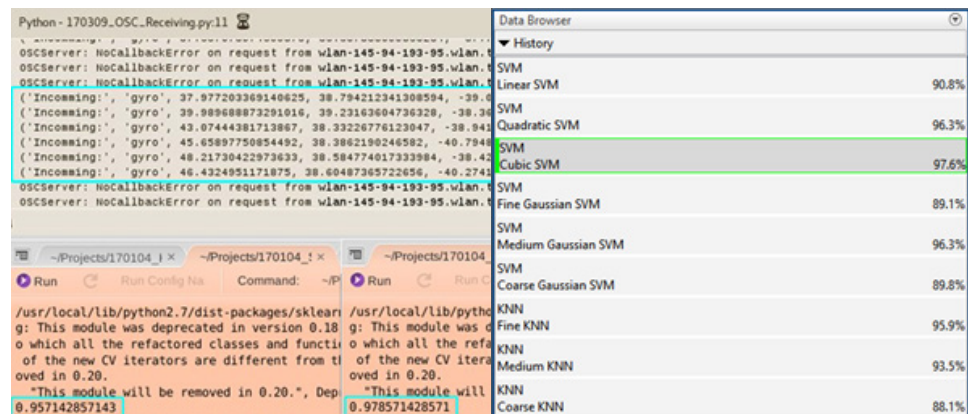
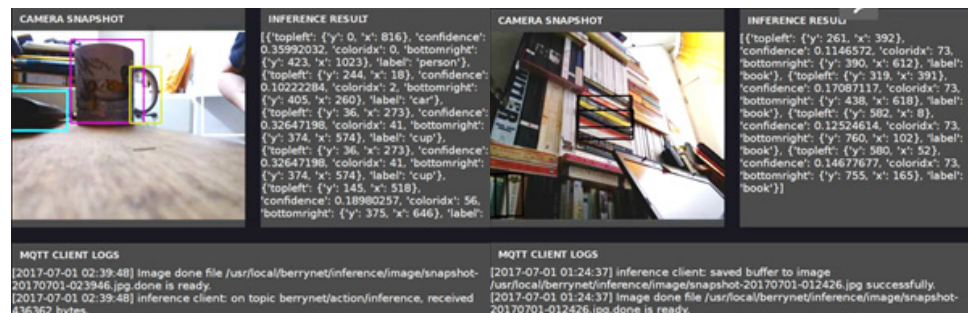


Figure 2.
Multiple-object de-
tection via BerryNet
(DT42©, Ltd., 2017);
Left: 'person', 'cup';
Right: 'books'



other sensing mechanisms.

In this section, three previously developed mechanisms are detailed. The first pertains strictly to Object Recognition (see Liu Cheng, Bier, Mostafavi, 2017); the second and third to Facial-Identity and -Expression Recognition (forthcoming publication—see Notes), respectively. The first mechanism is implemented with open-source BerryNet® (DT42©, Ltd., 2017), which is built with a classification model—viz., Inception® ver. 3 (Szegedy et al., 2015)—as well as a detection model—viz., TinyYOLO® (Redmon and Farhadi, 2016). The classification model uses Convolutional Neural Networks (CNNs), which are at the forefront of ML research (Szegedy et al., 2015). An advantage of BerryNet® is that it is a fully implementable gateway on a cluster of RPi3s. On an individual RPi3, the inference process is slow, requiring a delay between object-recognition sessions. This situation is ameliorated by the dynamic clustering feature of the WSAN. Another benefit-cum-limitation is that BerryNet®'s classification and detection models are pretrained, which avoids the need to generate said models locally.

The Object Recognition mechanism (see figure 2) in the D2RO System Architecture is intended to be deployed across a variety of cameras in the overall built-environment, and that instances of detection were to be cross-referenced to minimize false positives. In order to implement this setup, each RPi3 node in the WSAN is equipped with a low-cost Raspberry Pi Camera® V2.1, then BerryNet® is installed in every node and the inference mechanism tested individually. The next step is to enable the nodes to share their detection results, which could be done via WiFi. Nevertheless, in order to reduce energy-consumption for every object-detection cross-referencing instance, ZigBee is preferred. In order to enable ZigBee on BerryNet®'s detection_server.py and classify_server.py

were modified and made compliant with python-xbee (n.io Innovation©, LLC, 2017).

The second and third mechanisms—i.e., Facial-identity and -Expression Recognition—are implemented via two independent yet interrelated components. The first is implemented locally via Google Brain®'s TensorFlow™ (TensorFlow™, 2018): while the second via Google Cloud Platform®'s Cloud Vision API (Google Cloud Platform®, 2018b). In the implementation of the first component, TensorFlow™ is installed on a Linux (Ubuntu) virtual environment and executed in Python. During execution of its Multi-Task Convolutional Neural Network (MTCNN) face detection model, TensorFlow™ requests the user to capture images of his/her face from a variety of positions, orientations, and angles. After completing this phase, facial identity recognition is successfully tested real-time (see figure 3, Top). In the implementation of the second component, Python is used to integrate the services of Cloud Vision API into the inherited VWSAN. The same visual input is provided to both components to yield a correlated recognition of an identity as well as of a facial expression (see figure 3).

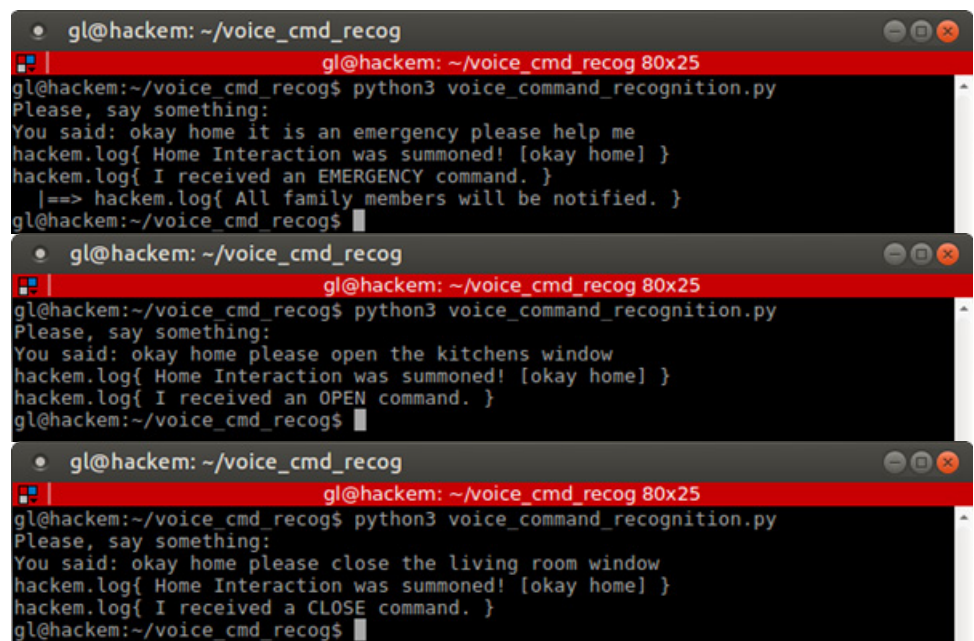
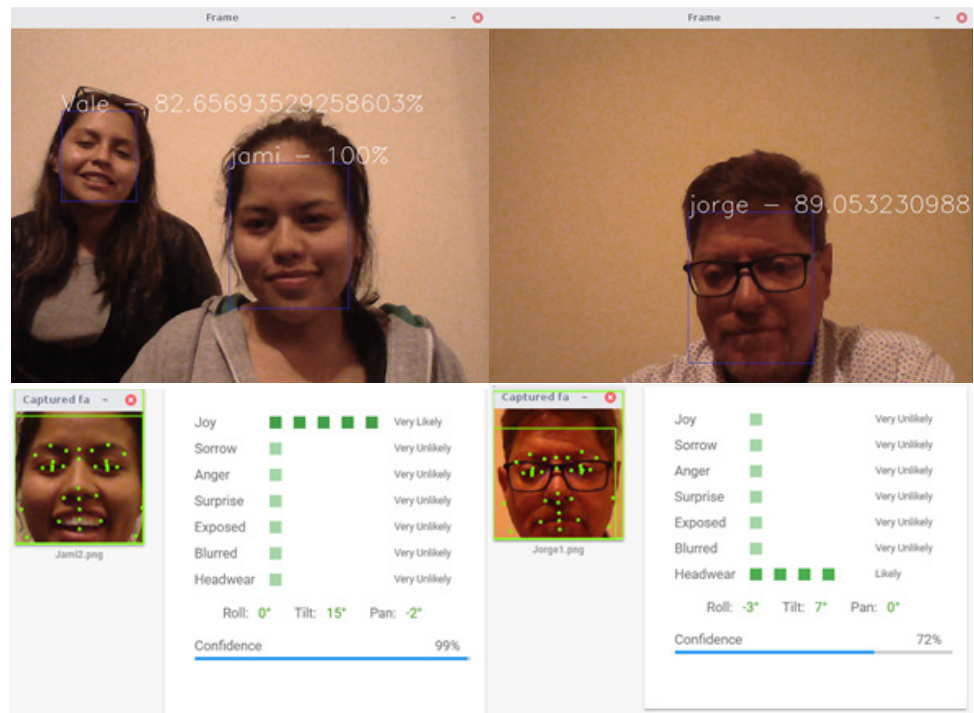
Machine Learning and Speech and Voice-Command Recognition

Speech and Voice-Command Recognition enable the built-environment to listen to the occupant(s). Perceived speech and subsequent processing of command may serve to override and/or to adjust automatic actuations effected by the built-environment according to the preferences suggested by occupant-profiles. They may also serve to explicitly engage an actuation or to feed information to the system. For example, should the mechanism that ascertains comfortable temperature and humidity conditions within the built-environment actuate against the occupants wishes for that particular moment, he/she could verbally command the built-environment to stop. In a different scenario, one where the occupant is in a state of emergency, he/she could verbally ask the built-environment to call for help (see figure 4, Top).

In this section, a purpose-built implementation of this mechanism is detailed. This mechanism is designed to work in tandem with but independent of a previously implemented Alexa Voice Service (Amazon®, 2017b) (AVS) mechanism (see Liu Cheng and Bier, 2018). The AVS mechanism enabled the built-environment to access an array of preset voice commands made available by Amazon®, and to connect the former's services to the Internet. However, the usefulness of AVS centered around consumer-based services online, not within the local built-environment. Admittedly, AVS may be extended to work with customized commands within local built-environments via Alexa Skills Kit (Amazon®, 2017a), but these must rely on Amazon®'s developer and cloud services. Although AVS does provide advantages to the services provided by the local built-environment, a more flexible and easy to customize Speech and Voice-Command Recognition mechanism is preferred for the control of local actuations. Via a Python script, this mechanism first uses PyAudio (Pham, 2017) to listen to an initial key trigger command and to process following spoken speech locally (compare to AVS's remote processing), and then sends the result to Google Cloud Platform®'s Cloud Speech-to-Text (Google Cloud Platform®, 2018a) to generate a string text in return. This text—now effectively a local variable—is then used to trigger particular events in the local built-environment. Since the trigger mechanism is locally programmed, there is no limit—beyond that of the system's storage capacity—as to how many new speech-to-actuation correlations may be configured (see figure 4).

Conclusions

The purpose of this essay is to promote AI's role in the realization of highly sophisticated intelligent



built-environments by illustrating three fundamental ML mechanisms in D2RO's prescriptive System Architecture. Each of the described mechanisms highlights the sophisticated way via which ML processes seemingly random high-volume data to yield meaningful results. These mechanisms are also highlighted because no viable non-ML counterparts exist, at least not ones capable of inherent evolution and increase in precision over time. AI via ML enables the built-environment to detect patterns otherwise undetectable, patterns that mean the difference between an intuitive solution and a cumbersome imposition. Especially in the context of intelligent built-environments, this difference and the likes determine user acceptability as well as system effectiveness with respect to promotion of occupant well-being. The intelligent built-environment without AI is simply not intelligent enough.

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Notes

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References

- Acampora, G., Cook, D. J., Rashidi, P. and Vasilakos, A. V. (2013) 'A Survey on Ambient Intelligence in Healthcare', *Proceedings of the IEEE*, vol. 101, no. 12, pp. 2470–2494.
- Alsheikh, M. A., Lin, S., Niyato, D. and Tan, H.-P. (2014) 'Machine Learning in Wireless Sensor Networks: Algorithms, Strategies, and Applications', *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 1996–2018.
- Amazon® (2017a) Alexa Skills Kit: Teach Alexa a new skill and reach millions of customers [Online]. Available at <https://developer.amazon.com/alexa-skills-kit> (Accessed 19 April 2017).
- Amazon® (2017b) Alexa Voice Service: Bring Alexa to your connected products with Amazon's intelligent cloud-based voice service [Online]. Available at <https://developer.amazon.com/alexa-voice-service> (Accessed 19 April 2017).
- Andreu, J. and Angelov, P. (2013) 'An evolving machine learning method for human activity recognition systems', *Journal of Ambient Intelligence and Humanized Computing*, vol. 4, no. 2, pp. 195–206 [Online]. DOI: 10.1007/s12652-011-0068-9.
- Anguita, D., Ghio, A., Oneto, L., Parra, X. and Reyes-Ortiz, J. L. (2013) 'A Public Domain Dataset for Human Activity Recognition Using Smartphones', *Proceedings of the 21th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning, ESANN 2013*.



Bruges, Belgium, 24-26 April.

Bock, T., Güttler, J., Georgoulas, C. and Linner, T. (2015) 'The Development of Intra-House Mobility, Logistics and Transfer Solutions in PASSAge', *Journal of Robotics and Mechatronics*, vol. 27, no. 1, p. 108.

Buitinck, L., Louppe, G., Blondel, M., Pedregosa, F., Mueller, A., Grisel, O., Niculae, V., Prettenhofer, P., Gramfort, A., Grobler, J., Layton, R., Vanderplas, J., Joly, A., Holt, B. and Varoquaux, G. (2013/09/01) API design for machine learning software: experiences from the scikit-learn project [Online]. Available at <http://arxiv.org/pdf/1309.0238>.

Cook, P. (1970) *Experimental architecture*, New York, Universe Books.

Cook, P. (1972) *Archigram*, London, Studio Vista.

Dalcin, L. D., Paz, R. R., Kler, P. A. and Cosimo, A. (2011) 'Parallel distributed computing using Python', *Advances in Water Resources*, vol. 34, no. 9, pp. 1124–1139.

DT42©, Ltd. (2017) *BerryNet®: Deep learning gateway on Raspberry Pi* [Online]. Available at <https://github.com/DT42/BerryNet> (Accessed 21 June 2017).

Eastman, C. M. (1972) *Adaptive conditional architecture*, Pittsburgh, Institute of Physical Planning, School of Urban and Public Affairs, Carnegie-Mellon University.

Fox, M. (2010) 'Catching up with the Past: A Small Contribution to a Long History of Interactive Environments', 5-18 Pages / *FOOTPRINT*, Issue # 6 | Spring 2010 | Digitally-Driven Architecture.

Georgoulas, C., Raza, A., Güttler, J., Linner, T. and Bock, T. (2014) 'Home Environment Interaction via Service Robots and the Leap Motion Controller', *Proceedings of the 31st International Symposium on Automation and Robotics in Construction (ISARC 2014)*.

Google Cloud Platform® (2018a) *Cloud Speech-to-Text: Speech to text conversion powered by machine learning and available for short or long-form audio* [Online], Google®. Available at <https://cloud.google.com/speech-to-text/> (Accessed 25 April 2018).

Google Cloud Platform® (2018b) *Cloud Vision API: Derive insight from images with our powerful Cloud Vision API* [Online], Google®. Available at <https://cloud.google.com/vision/> (Accessed 20 April 2018).

Jaskiewicz, T. (2013) *Towards a Methodology for Complex Adaptive Interactive Architecture*.

Kolarevic, B. (2014) 'Outlook: Adaptive Architecture: Low-Tech, High-Tech, or Both?', in Kretzer, M. and Hovestadt, L. (eds) *ALIVE: Advancements in adaptive architecture*, Basel/Berlin/Boston, Birkhäuser, pp. 148–157.

Lindgren, H., Paz Santana, J. F. d., Novais, P., Fernández-Caballero, A., Yoe, H., Ramirez, A. J. and Villarrubia, G. (2016) *Ambient intelligence: Software and applications -- 7th International Symposium on Ambient Intelligence (ISAmI 2016)*, Switzerland, Springer.

Liu Cheng, A. (2016) 'Towards embedding high-resolution intelligence into the built-environment', Archidoct, vol. 4, no. 1, pp. 29–40 [Online]. Available at http://www.enhsa.net/archidoct/Issues/Archidoct_vol4_iss1.pdf (Accessed 15 September 2016).

Liu Cheng, A. and Bier, H. H. (2016a) 'Adaptive Building-Skin Components as Context-Aware Nodes in an Extended Cyber-Physical Network', Proceedings of the 3rd IEEE World Forum on Internet of Things. Reston, VA, USA, 12-14 December, IEEE, pp. 257–262.

Liu Cheng, A. and Bier, H. H. (2016b) 'An Extended Ambient Intelligence Implementation for Enhanced Human-Space Interaction', Proceedings of the 33rd International Symposium on Automation and Robotics in Construction (ISARC 2016). Auburn, Alabama, 18-21 July, pp. 778–786.

Liu Cheng, A. and Bier, H. H. (2018) 'Extension of a High-Resolution Intelligence Implementation via Design-to-Robotic-Production and -Operation strategies', Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC 2018). Berlin, Germany, July 20-25. Berlin, Germany.

Liu Cheng, A., Bier, H. H., Latorre, G., Kemper, B. and Fischer, D. (2017) 'A High-Resolution Intelligence Implementation based on Design-to-Robotic-Production and -Operation strategies', Proceedings of the 34th International Symposium on Automation and Robotics in Construction (ISARC 2017). Taipei, Taiwan (R.O.C.), 28 June - 1 July.

Liu Cheng, A., Bier, H. H. and Mostafavi, S. (2017) 'Deep Learning Object-Recognition in a Design-to-Robotic-Production and -Operation Implementation', Proceedings of the 2nd IEEE Ecuador Technical Chapters Meeting 2017. Salinas, Ecuador, 18-20 October. Guayaquil, Ecuador.

Liu Cheng, A., Bier, H. H. and Mostafavi, S. (2018) 'Integration of a Wearable Interface in a Design-to-Robotic-Production and -Operation Development', Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC 2018). Berlin, Germany, July 20-25. Berlin, Germany.

Milgrom, P. R. (1990) 'The economics of modern manufacturing: technology, strategy, and organization', The American Economic Review, vol. 80, no. 3, pp. 511–528.

n.io Innovation©, LLC (2017) python-xbee: Python tools for working with XBee radios [Online]. Available at <https://github.com/nioinnovation/python-xbee> (Accessed 1 June 2017).

Negroponte, N. (1969) 'Toward a Theory of Architecture Machines', Journal of Architectural Education (1947-1974), vol. 23, no. 2, p. 9.

Negroponte, N. (1975) 'The architecture machine', Computer-Aided Design, vol. 7, no. 3, pp. 190–195.

Oosterhuis, K. (2012) Hyperbody: First decade of interactive architecture, Heijningen, Jap Sam Books.

Ortiz, J. L. R. (2015) Smartphone-based human activity recognition, Cham, Springer.



Palumbo, F., Gallicchio, C., Pucci, R. and Micheli, A. (2016) 'Human activity recognition using multi-sensor data fusion based on Reservoir Computing', *Journal of Ambient Intelligence and Smart Environments*, vol. 8, no. 2, pp. 87–107.

Pask, G. (1975a) *Conversation, cognition and learning: A cybernetic theory and methodology*, Amsterdam, New York, Elsevier.

Pask, G. (1975b) *The cybernetics of human learning and performance: A guide to theory and research*, London, Hutchinson Educational.

Paz Santana, J. F. d., Julian, V., Villarrubia, G., Marreiros, G. and Novais, P. (2017) *Ambient intelligence: Software and applications : 8th International Symposium on Ambient Intelligence (ISAmI 2017)*, Cham, Switzerland, Springer.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Louppe, G., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M. and Duchesnay, É. (2017/01/10) *Scikit-learn: Machine Learning in Python* [Online]. Available at <http://arxiv.org/pdf/1201.0490>.

Pham, H. (2017) *PyAudio* [Online], Massachusetts Institute of Technology. Available at <http://people.csail.mit.edu/hubert/pyaudio/> (Accessed 29 May 2018).

Rajkumar, R., Lee, I., Sha, L. and Stankovic, J., eds. (2010) *Cyber-physical systems: the next computing revolution*, ACM.

Redmon, J. and Farhadi, A. (2016/12/25) *YOLO9000: Better, Faster, Stronger* [Online]. Available at <http://arxiv.org/pdf/1612.08242>.

Salomons, E. L., Havinga, P. J. M. and van Leeuwen, H. (2016) 'Inferring Human Activity Recognition with Ambient Sound on Wireless Sensor Nodes', *Sensors* (Basel, Switzerland), vol. 16, no. 10.

Steenson, M. W. (2014) *Architectures of information: Christopher Alexander, Cedric Price, and Nicholas Negroponte and MIT's Architecture Machine Group*.

Szegedy, C., Vanhoucke, V., Ioffe, S., Shlens, J. and Wojna, Z. (2015/12/11) *Rethinking the Inception Architecture for Computer Vision* [Online]. Available at <http://arxiv.org/pdf/1512.00567>.

TensorFlow™ (2018) *An open source machine learning framework for everyone* [Online], Google Brain®. Available at <https://www.tensorflow.org/> (Accessed 20 April 2018).

V2_Lab (2008) *pyOSC* [Online]. Available at <https://github.com/ptone/pyosc> (Accessed 10 June 2016).

Villa, A. E. (2012) *Artificial neural networks and machine learning-- ICANN 2012: 22nd International Conference on Artificial Neural Networks, Lausanne, Switzerland, September 11-14, 2012, Proceedings*, Berlin, New York, Springer.

Xiao, W. and Lu, Y. (2015) 'Daily Human Physical Activity Recognition Based on Kernel Discriminant

- Analysis and Extreme Learning Machine', Mathematical Problems in Engineering, vol. 2015, no. 1, pp. 1–8.
- Yang, S.-H. (2014) Wireless Sensor Networks Principles, Design and Applications, London, Springer London.
- Zelkha, E., Epstein, B., Birrell, S. and Dodsworth, C. (1998) 'From Devices to 'Ambient Intelligence': The Transformation of Consumer Electronics (Conference Keynote)', Digital Living Room Conference.



From smart cities to playable cities. Towards playful intelligence in the urban

environment

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From smart cities to playable cities. Towards playful intelligence in the urban environment

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Abstract

In the last decade, we have seen the rise of urban play as a tool for community building, and city-making and Western society is actively focusing on play/playfulness and intelligent systems as a way to approach complex challenges and emergent situations.

In this paper, we aim to initiate a dialogue between game scholars and architects. Like many creative professions, we believe that the architectural practice may benefit significantly from having more design methodologies at hand, thus improving lateral thinking. We aim at providing new conceptual and operative tools to discuss and reflect on how games and smart systems facilitate long-term the shift from the Smart Cities to the Playable one, where citizens/players have the opportunity to hack the city and use the smart city's data and digital technology for their purposes to reactivate the urban environment.

Keywords

Playfulness, architecture, digital media, smart city, playable city

Introduction - Contribution of EES to the built environment

Cities are becoming more and more complex, both regarding their social, cultural and political context and in the technological implementations that make them function and be more and more liveable for citizens. Currently, we are facing the need to rethink, with the help of smart technologies, traditional urban models. Indeed, cities have always been the primary drivers of change in economic development and growth, innovation and environmental balance, and numerous urban areas in Europe have seen a significant difference in the structure and organization of public service provision (European Commission 2015).

In the last decades, advanced technologies like the Internet of Things (IoT), sensors and networked information infrastructures have facilitated the diffusion of digital and intelligent features in the urban environment. This is leading to a significant shift in the organization of our society that has been called the “rise of the platform society” (de Waal, 2014). The platform society, based on the ‘hacker ethic’, can empower the citizen to organize themselves around issues, bringing about a sharing economy, a participation society or civic economy.

What we want to underline is how digital mediations have become common in the urban environment, opening a new dialogue between different stakeholders and researchers involved in various fields like architecture, urban planning, HCI, game design and UX.

Indeed, after the WWII, the transition towards “The Information Society” (Toffler, 1980) has fostered the rise of new urban models, and cities have become a proper ‘playground’ where different approaches were tested and implemented in order to explore new ways to reach a more efficient, intelligent and sustainable development. The architecture itself and the urban environment has benefited from the IT field and its implementation in the body and essence of buildings (Saggio, 2013).

“Smart City” is only the last famous label to identify cluster-technology driven approaches to urban renewal and development where the use of Big Data incentivized new forms of organization, management and citizens participation. Nowadays, the use of digital technologies by municipalities and governments leads to a more efficient use of resources and a better organization of the urban environment.

What we argue for is the more comprehensive use of the ideas of “smart” and “intelligence” to tackle different aspects not taken into account when referring to Smart Cities. There are some other elements of the smartness in contemporary cities which is not only related to efficiency and management; for example, daily life activities which are undertaken without any specific purpose but just for fun, leisure and social interaction among citizens.

Going beyond the idea of smartness and intelligence only related to economy and services can produce new insights on how we need smart technology to allow residents to reconfigure city services and to make a city playful and playable.

In this article, we will first briefly define where the origin of the idea of a ‘playable city’, and then we will highlight how embedded smart technology can play a role in the generation and understanding of affective, playful, and humorous activities and events. The last section we will present three case studies where the use of smart technology fosters playful interactions between citizens and city technology in public spaces to create not only smart cities but, more important, smart citizens.



Playful, Smart and Intelligent cities. Multiple labels, one common intelligent strategy

The use of games in architecture and urban planning is not new. Their implementation has a long history since the 1960s (Abt, 1969; Duke, 1975), and has remained a favorite tool for spatial modeling and simulation, and public participation (Devisch et al., 2016; Mayer, 2009; Poplin, 2012). In the last decade, we have seen the rise of urban play as a tool for community building and city-making (Tan and Portugali 2012; Tan 2017), and Western society is actively focusing on play/playfulness as a way to approach complex challenges and emergent situations. Early applications of serious games in urban planning focused on developing strategies to overcome multiple issues and to find effective ways to understand and inform urban patterns. Some first attempts worth naming in this context are Abt's first urban game 'Corridor' (Abt, 1969) - a computer-assisted simulation game, to explore the technological, economic and political constraints on the development of an alternative transportation plan for the Northeast Corridor - and Jay Forrester's (1969) work on urban dynamics and urban simulation games such as the ones developed by Meadows and Randers for the Club of Rome.

The idea of a 'playable city' was first introduced during the 90's by the new generation of video games that, thanks to a significant development in consoles and personal computers, could simulate real cities environment.

SimCity and Grand Theft Auto (GTA) were some of the most popular attempts to mix games and urban design processes. In the first one, the player had to deal with the plan city development distribute resources, regulate energy consumption, and even regulate population. Rockstar game developers for GTA used an entirely different insight; in the game various playable cities - London, Los Angeles, San Francisco, etc. - were implemented and the players could experience a digital environment that was the exact copy of the real one where elements of artificial intelligence were deployed. The main critical issue pointed out on (Nijholt, 2016) these video games is that rarely they took in account how virtual and real residents interacted or took care of their daily obligations and the barrier within games and reality was not completely overcome.

It's valuable to point out how speculative researches regarding the digital city of the future have always been a topos during the last century. In sci-fi literature (Orwell's 'Big Brother,' Bradbury's 'Fahrenheit, 451,' Huxley's 'Brave New World', Dick's 'Do Androids Dream of Electric Sheep?'), it is common to find future cities where smart and intelligent technologies are deeply embedded in the urban fabric and accessible - with different protocols - by different kinds of users. In the early 90s, Singapore claimed itself to become an intelligent island (NBC, 1992) and the concepts of intelligent nations and cities were at that point introduced.

The shift from the intelligent city to the smart one is well explained in Deaking and Alwaer (2011). They underline how this passage is verifiable in the growing attention towards the role of sensors and actuators embedded in physical and the appearance of ubiquitous and disappearing computers. Indeed since the 2000s, 'Smart City' has been used as a label to environments where clusters of Big Data, through the use of sensors and actuators, help to monitor and organize the activity of visitors or simple citizens.

According to Bowerman et al. (2000), what characterizes smart cities is their “use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms.”

Many researchers (Hollands 2008; Townsend, 2013; de Lange and de Waal, 2013) expressed critical views on cities that are smart, claiming that the smartness of the technology is not for everyone but is controlled by giant stakeholders, and their use is based on a top-down driven process based on a productive/economic side. They stand for urban environments that are characterized by social relations and by the emergence of a variety of practices, and not for a diffused tendency to frame urban-scale interventions as top-down driven processes, often technology-pushed and industry-driven, instead of bottom-up and participatory.

An interesting point of view discusses ‘bottom-up’ approaches to the concept of smart cities (Townsend, 2014). Townsend stands for open access to data so that citizens’ collectives can write programs that address problems or opportunities that are of less interest to city officials and companies but that aim to solve problems that are felt in local city communities. This approach ensures a hacker mentality that characterizes contemporary city-makers that aim to kick-start a range of urban infrastructures, systems, and services using reasonably simple off-the-shelf digital tools.

Playful cities. Intelligent playgrounds in the urban environment

Cities always had spaces design for fun and entertainment. Play happens in specific designed urban sites where citizens are allowed to spend their free time and interact with the others. Oldenburg (2011) defines these spaces as “Third Places”. He distinguishes between First Places (our home environment), Second Places (our work environment), and Third Places, in which people gather and meet each other in a playful mood and can establish bonds with the others.

The use of digital technologies - sensors and actuators, artificial intelligence and digital media - allows users to enhance these spaces and make the city more playful and attractive. These systems change the space and time of play entirely, transforming the city in a whole playground where ludic processes can be real-time activated and social interaction is fostered.

Indeed, play is fun and play is everywhere. This statement relates to the idea that the spaces in a playable city will be used in ways not predicted by designers. This is called ‘appropriation’ (Dix, 2007), when the gamer moves through the space looking for bugs or provoking the environment, and does not follow the routine or underlying narratives (Nijholt, 2015, 2016a, b).

Even though games and play have entered the mainstream in a wide range of different contexts, and the combined study of games and cities (Nijholt, 2016) is gaining more and more attention from academic researchers, we still lack a specific definition of what a game is. We agree that a game is a “form of structured play” (Salen & Zimmerman, 2004) and that four conditions are required to call an event a game (Suits, 1978): 1. A clear goal; 2. The need of performing explicit acts (rules) to reach this goal; 3. A collective agreement among players to embrace the rules and work towards the goal; 4. Players need an assessment loop for continuous motivation. If a recent statement invites people to “play anything” (Bogost, 2016), we see no side effects in attempting to bring game dynamics and mechanics in a complicated and risky field like the architectural and urban planning one.

Since participation and civic engagement have increasingly a significant part of urban planning and



governance (Gordon and Mihailidis, 2016), we identify the need of using games (both analog and digital/intelligent oriented games) as new tools to trigger participation and to address a variety of aspects in urban planning such as design issues, stakeholders negotiation and deliberation, and self-organisation practises (Glick, 2012; Grahan & Marvin, 2001; Krasny, 2013). The use of play tackles three main fields related to the idea of civic engagement and empowerment: procedures, self-determination, and motivation.

Even though play, playfulness, and playability are gaining more full attention in architecture and HCI we still lack a specific field of study, their boundaries are still blurry, and we are currently facing a substantial overlap between definitions and explanations.

According to Bateson and Martin (2013), play is not only related to children's play. It takes place also when grown-up people join together and engage through playful social interaction. Furthermore, playfulness is not only displayed in physical interactive behavior, but traces of it can also be found when relating to the others with playful thoughts.

Intelligent technology and embedded smartness can help us to visualize our playful thoughts and make them perceptible using new media, fostering the idea that these can be translated in changes - both relational and physical - in our environment.

In connection in addition to that, among the features of Play defined by Bateson and Martin, the sixth one is the more useful in our theoretical speculation and introduce the concept of 'playful play':

Playful play is accompanied by a particular positive mood state in which the individual is more inclined to behave (and, in the case of humans, think) in a spontaneous and flexible way.

In this definition, we notice how 'play with thoughts' is seriously taken into account as one of the principal features of ludic activity. Playfulness requires then smart technologies to realize new events in the real world and its implementation in the so-called Smart Cities is reached through the free access to citizens to these technologies to facilitate them in taking decisions to on how to transform a non-playful situation into a playful one.

Indeed, a smart city becomes playful through its digital smartness, regardless if it has been provided by public/private stakeholders or by hacktivists that hacked the intelligent infrastructures of the city to make them more accessible and open for everyone. This strongly relates to the idea of 'platform society' (de Waal, 2014) that was mentioned above, where the notion of appropriation materializes through non-linear and independent procedures led by digitally activated groups.

Smart technologies should then be developed with the idea of providing new ways to experience the city and stimulate serious play. This is a crucial point to accomplish the paradigm shift that leads to a city that can be labeled as 'playful.' Moreover, according to Grønbæk et al. (2012), a city that aims for being playful does not only have to foster the implementation of playful installations in the urban fabric but motivate citizens to appropriate the physical space they live to discover new paths, write new stories and co-create new perspectives for tomorrow.

At this point, we can introduce a set of strong concepts to highlight to define the qualities of what a so-called 'playful city' should be. These principles are inherited from a group of Dutch multidisciplinary researchers (Schouten, 2011; Tan, 2014) that have been working for years on a hybrid field

between architecture, game design, HCI and Information Technology. These principles are:

- Bottom-up approach instead of top-down decision making;
- Co-creation: allowing a large audience to participate;
- Iterative Design: instant prototyping, virtual and real visualizations;
- The wisdom of the Crowd: where information and decisions can come from many sources;
- Civic medium: to connect the virtual and the real worlds;

After having preliminarily organized our 'Playful City' categories through some literature examples and contemporary debates, we now proceed to substantiate them with recent examples from the broad field of application to check whether our model resonates with the latest implementations and realizations.

New media for playful cities. Smart technologies between game design and architecture

The three case studies we analyze in this paper deal with the topic of how to foster playful, bottom-up participation in urban environment. As it usually happens in urban play, a significant narrative part is implemented, with the storytelling phase actively trying to address a new participatory decision-making process. As we will see, they do open up new possibilities for engagement and contribute to the diversification of methods and tools available to the facilitators of these processes. Nevertheless, focusing on "smart citizens" - the inhabitants of the smart city - provides a brand new playful, bottom-up and human-centered way to design the urban space. The so-called "Third Wave" HCI design (Bødker, 2006) has been working for years on this objective.

Furthermore, they want to focus attention on the concepts of civic engagement and citizen participation that can be broadly defined as the sum of political and social practices, by which individuals engage with and influence public affairs, beyond their direct private environment (Gordon, Balwin-Philippi, & Balestra, 2013; Parés & March, 2013; Raphael, Bachén, Lynn, Balwin-Philippi, & McKee, 2010).

Among the main differences, we want to focus the reader's attention on the different technological approach that characterizes these case studies. Shadowing represents a significant example of a high-tech solution where projection and sensors are used to find new ways to interact and relate.

Buiksloterham Matrix is a tabletop game that casts players into roles that span from homeowners, local builders, public officials, etc.

Reciprocal is an interactive plug-in design installation where different intelligent technologies are implemented to let citizens playfully appropriate the city. These games are experienced as suitable formats to illustrate the complexity of urban matters and to make them more tangible. These examples want to cover a wide range of different ways to tackle contemporary issues using different outputs such as digital media, game design challenges and playful architecture.

Shadowing (2014)

'Shadowing' was chosen from a shortlist of eight projects as part of the Playable City Award 2014.

During the last years, the city of Bristol (UK) has designated itself to be the world's first playable city by introducing some interactive installations in their streets during a 'playable city' period. The installations implemented in the city are truly integrated into the urban fabric. 'Shadowing' gives memory to city lights, enabling them to record and playback the shadows of those (people or even animals) who passed underneath.

Once playful passersby learn about the system, they can try to compose strange shadows playfully to interact with strangers' shadows fostering new ways of appropriation.

The game inspires and motivates players to connect, either physically or virtually, with other like-minded people, thus fostering experiences of relatedness and builds scenario settings to invite citizen/players to take direct action.

Buiksloterham Matrix (2015)

1. www.thehackablecity.nl.

Buiksloterham Matrix is part of the 'Hackable City1' research project that explores the potential for new modes of collaborative city-making in a network society.

The game is a tabletop game that inherits its game mechanics from an open framework called Matrix Game System (Engle 1988), a tool for producing referee-mediated strategic games with an emphasis not on quantitative mechanics but qualitative and rhetorical arguments (Schouten, Ferri, de Lange, Millenaar, 2016).

The game takes place in on a large-scale printed map of the neighborhood, moderated by an umpire and with tokens representing where and when the specific actions take place. The different involved players (private stakeholders, NGOs, ordinary citizens and municipality's delegates) are asked to address the overall objective within 12 turns. At every turn,



Figure 1.
Shadowing implemen-
tation in Bristol

players declare an action to attempt and present an argument to the umpire describing why it would succeed. The game supports creating different what-if scenarios, transforming players' roles from passive recipients into informed decision-makers with the real agency on such a complex, and thorny, topic like planning issues. A sense of empathy and relatedness is fostered by the modeled built environment game-pieces facilitate and by needing to motivate for game decisions verbally. For this reason, the game focuses specifically on the creation of a collective actor (the us).

Reciprocal (2016-2017)

Prototyped and developed by nlTrogrou2, Reciprocal is a plug-in design installation. With the term plug-in design, we refer to the IT definition of 'plug-in': a non-independent program that interacts with another one to expand its native features.

An actual depressed urban condition triggers the project's process as an opportunity to offer citizens a new perspective on public spaces, lighting up qualities that are not perceivable.

Reciprocal has been entirely computationally designed and is based on Leonardo Da Vinci's idea of 'reciprocal structure': a beam system arranged as a triangle, where each member is supported at the outer end by a ring beam or a column and at the inner end by the adjacent one.

2. nlTrogrou is a research team founded in 2006 by professor Antonino Saggio. The team deals with the idea that IT and intelligent technologies are the new catalyst for a renovation of the architectural culture and practise. Reciprocal was developed, prototyped and built by: Antonino Saggio, Gabriele Stancato, Matteo Baldissara, Valerio Galeone, Selenia Marinelli, Davide Motta, Valerio Perna, Alessandro Perosillo, Silvia Primavera, Manuela Seu and Michele Spano.

Discussion, Conclusions, And Future Work

The examples presented in this paper clearly show how "traditional" methods for playfully enhance the urban spaces can comfortably co-exist, thus be increased, by the use of interdisciplinary novel tools such as digital media, games and open platforms. Furthermore, the domain at the crossroads on urban planning, civic media, activism, and game design is becoming more and more important (Nijholt, 2017; Tan, 2017; Gordon and Mihailidis, 2016). As a next step, more testing and validation are certainly needed, and we see this process as inherently iterative and practical. We are still in search of developing a more nuanced vocabulary that can accurately set the debate between architects and game scholars, and ambiguities in the terminology currently employed in analyzing games experience. If we want to keep walking this way, focusing on playful interaction and urban play, we are still in need of a shared design terminology.

There is much more work to be done, the potential of this approach is far from being exhausted. We surely need more games, indeed real cases, to set an ever-growing design-oriented dialogue that can lead to further implementations and follow-up studies with the use of smartness and intelligent systems in the design and deployment phase between architecture, design, and play.



Figure 2.
Reciprocal 1.0 - Gioiosa Marea (Sicily)

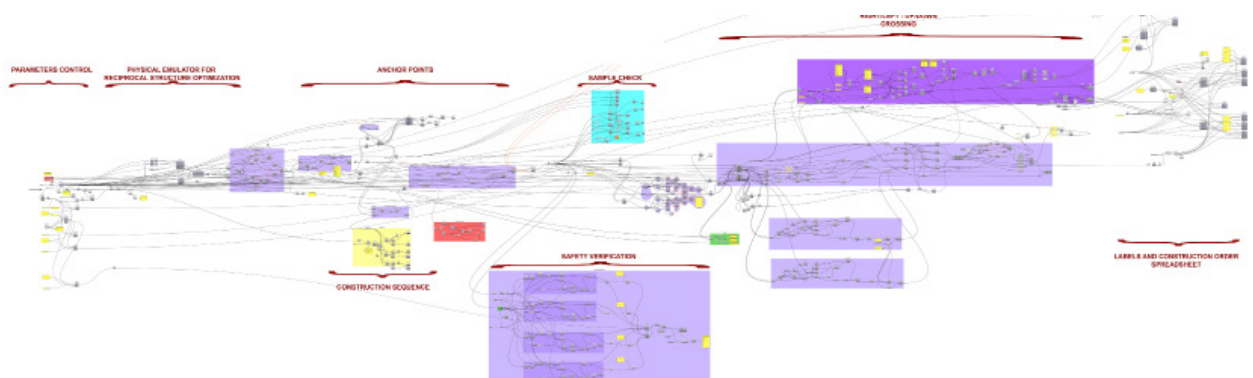


Figure 3.
The algorithm behind
Reciprocal developed
by nITrogroup –
Algorithmic design:
Gabriele Stancato

References

- Abt, C. (1969) *Serious games*. New York: Viking Press.
- Bateson, P., Martin, P. (2013) *Play, Playfulness, Creativity and Innovation*, Cambridge: Cambridge University Press,
- Bogost, I. (2016) *Play Anything: The Pleasure of Limits, the Uses of Boredom, and the Secret of Games*. Hachette UK.
- Bowerman, B., Braverman, J., Taylor, J., Todosow, H., Von Wimmersperg, U. (2000) The Vision of a Smart City. In: 2nd International Life Extension Technology Workshop, pp. 48–58. Paris.
- de Lange, M., de Waal, M. (2013) *Owning the city: New media and citizen engagement in urban design*. First Monday. 18.
- de Waal, M. (2014) *The City as Interface: How Digital Media are Changing The City*. Rotterdam: Nai010 Publishers.
- Deakin, M., Alwaer, H. (2011) From intelligent to smart cities. *Intell. Build. Int.* 3(3), 140–152 doi:10.1080/17508975.2011.586671
- Devisch, O., Poplin, A., & Sofronie, S. (2016). The gamification of civic participation: Two experiments in improving the skills of citizens to reflect collectively on spatial issues. *Journal of Urban Technology*, 23(2), 81–102.
- Dix, A. (2007) Designing for Appropriation. In: *Proceedings of the 21st British HCI Group Annual Conference on People and Computers: HCI... but not as we know it-Volume 2*, pp. 27–30. British Computer Society, London.
- Duke, R. (1975) *Metropolis: The urban systems game*. New York: Gamed Simulations, Inc.
- European Commission (2015) *European Research Area: Global Urban Challenges, Joint European Solutions*. Cofund Smart Urban Futures Call Text. <http://jpi-urbaneurope.eu>.
- Engle, C. (1988) *Matrix Games Systems (game)*. Chris Engle, Kansas City.
- Forrester, J. (1969) *Urban dynamics*. Waltham, MA: Pegasus Communications.
- Glick, D. (2012) *Bottom-up urbanism: A survey of temporary use in Europe*. Boston: Hart Howerton Community Fellowship. Retrieved from https://issuu.com/david.t.glick/docs/bottom-up_urbanism_dglick
- Gordon, E., Balwin-Philippi, J., & Balestra, M. (2013) *Why we engage: How theories of human behavior contribute to our understanding of civic engagement in a digital era*. Retrieved from http://cyber.law.harvard.edu/publications/2013/why_we_engage



Gordon, E., Mihailidis, P. (2016) *Civic Media: Technology, Design, Practice*. 1 edition. Cambridge, Massachusetts: MIT Press.

Grahan, S., & Marvin, S. (2001). *Splintering urbanism: Networked infrastructures, technological mobilities and the urban condition*. London: Routledge.

Hollands, R.G. (2008) Will the real smart city please stand up? *City* 12, 303–320

Krasny, E. (Ed.). (2013) *Hands-on urbanism 1850–2012: The right to green*. Hong Kong: MCCM creations.

Mayer, I. S. (2009). The gaming of policy and the politics of gaming: A review. *Simulation and Gaming*, 40(6), 825–862.

Nijholt, A. (2015) *Designing Humor for Playable Cities*. In: Ahram T, Karwowski W (eds.) In: Ji YG, Choi S (eds.) *Proceedings of the 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015), Section Advances in Affective and Pleasurable Design*. Las Vegas, USA, *Procedia Manufacturing*, Volume/issue 3C, pp. 2178–2185. Elsevier (ScienceDirect)

Nijholt, A. (2016a) *Mischief humor: From Games to Playable Cities*. In: *Proceedings 12th International Conference on Advances in Computer Entertainment Technology (ACE 2015)*, ACM Digital Library, Iskandar, Malaysia)

Nijholt, A. (2016b) *Mischief Humor in Smart and Playable Cities*. in: *Playable Cities: The City as a Digital Playground*, New York: Springer.

Nijholt, A. (2017) *Playable Cities: The City as a Digital Playground*, New York: Springer.

Oldenburg, R. (2001) *Celebrating the Third Place: Inspiring Stories about the “Great Good Places” at the Heart of Our Communities*, New York: Marlowe & Company.

Parés, M., & March, H. (2013). *Short guides for citizen participation. 3: Guide to evaluating participatory processes*. Barcelona: Department of Governance and Institutional Relations.

Poplin, A. (2012). Playful public participation in urban planning: A case study for online serious games. *Computers, Environment and Urban Systems*, 36(3), 195–206.

Raphael, C., Bachen, C., Lynn, K.-M., Balwin-Philippi, J., & McKee, K.A. (2010) Games for civic learning: A conceptual framework and agenda for research and design. *Games and Culture*, 5(2), 199–235.

Saggio, A. (2013) *The It Revolution in Architecture. Thoughts on a Paradigm Shift*. Raleigh USA: Lulu.com.

Salen, K., & Zimmerman, E. (2004). *Rules of play. Game design fundamentals*. Cambridge, MA: MIT Press.

Schouten, B.A.M. (2011) *PlayDesign & Citizen Empowerment*, Amsterdam: Archis Publishers

- Schouten, B.A.M., Ferri, G., de Lange, M., & Millenar K. (2017) Games as strong concepts for citymaking. In: Nijholt A., ed., *Playable Cities The City as a Digital Playground*, New York: Springer.
- Suits, B. H. (1978) *The Grasshopper: Games, Life and Utopia*. Toronto: University of Toronto Press
- Tan, E., Portugali, J. (2012) The Responsive City Design Game. In *Complexity Theories of Cities Have Come of Age*, edited by Juval Portugali, Han Meyer, Egbert Stolk, and Ekim Tan, 369–90. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-24544-2_20.
- Tan, E. (2014) *Negotiation and Design for the Self-organizing City*, Delft: TU Delft
- Tan, E. (2017) *Play the City. Games Informing the Urban Development*. Heyningen: JAP SAM Books.
- Toffler, A. (1980) *The Third Wave*, New York: Penguin Books.
- Townsend, A.M. (2013) *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia*. New York, NY: WW Norton & Company.
- Townsend, A.M. (2014) *Smart Cities*, New York/London: W.W. Norton & Company.



**Automated robotic toolpath generation of elastic mesh structure
An additive waving techniques for form-finding, MOGA optimisation, and robotic fabrication**

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Automated robotic toolpath generation of elastic mesh structure

An additive waving techniques for form-finding, MOGA optimisation, and robotic fabrication

George Tryfonos

Abstract

This research focuses on the development of an automated robotically-driven algorithm that can be used for the design, simulate and robotic fabrication of elastic tensile mesh structures. This approach aims to automate the process between the design development and additive fabrication phases through the development of a custom-made end-effector tool for physical execution. Specifically, the suggested procedure explores a weaving elastic mesh technique, followed by an automated form-finding and static analysis investigation as well as a direct tool-path generation implemented by an industrial robotic fabrication process. Within this framework, a feedback loop between the form-finding and optimisation algorithm is investigated, which is responsible for controlling the pretension of the elastic threads, aiming to suggest optimum additives robotic tool-paths. In parallel, robot's and end-effector tool's parameters and limitations are taken into account during digital form-finding and optimisation processes. The suggested procedure aims to extend the automated robotically-driven algorithm in order to achieve accurate repeatability control of the elastic material and in turn the effective physical fabrication of complex tensile shapes.

Keywords

Tensile structure, elastic material, optimisation, automated tool-path generation, industrial robotic fabrication

Introduction

The drift towards the digital development of complex, lightweight structures based on form-finding and their structural simulation, as well as the ability to incorporate optimisation procedures such as Multi-objective generic algorithms (MOGA) and the use of new elastic materials allow innovative robotically driven fabrication processes to come to the fore. Nevertheless, the knowledge regarding the design and fabrication of elastic tensile mesh systems requires an in-depth step by step simulation of their geometric, material characteristics and construction method (Bletzinger and Ramm, 2001). The study of such elastic material through physical experimentation and digital simulation enables a deeper understanding of their structural performance. However, full integration of these results within a design and fabrication method requires the development of innovative design algorithms and digital fabrication mechanisms (Duro-Royo, Mogas-Soldevila and Oxman, 2015). In order to achieve design complexity as well as accuracy and precision in the fabrication process a more advanced communication between design and fabrication is required.

The application of form-finding and material behaviour experiments in design traces back to the work of Frei Otto in the Stuttgart Institute of Lightweight Structures, where soap films or other materials were used for physical form-finding (Otto, Rasch and Schanz, 2006). Moreover, the innovation of digital tools for form-finding and, in parallel, the ability to simulate the behaviour of any material (Gramazio and Kohler, 2008) allow precise integration in complex construction shapes. For example, a large-scale tensile structure might be divided into smaller units and patterns, then analysed and finally fabricated. Conventional procedures might include the subdivision of meshes or membranes into smaller units, the flattening of each 3D geometry unit into 2D, the application of a stress reduction algorithm to reduce stresses from flattening and finally the shrinkage of the flattened units and their preparation for fabrication (Gale and Lewis, 2016). Such procedures depend on the accuracy of material simulation under tension and the assemblage strategy.

An essential factor towards automated design and fabrication method is the application of digital design and static analysis principles. By combining form-finding spring-based techniques with Multi-Objective Genetic Algorithms (MOGA), the accurate static simulation and optimisation of tensile mesh structures can be achieved. In the work (Ahlgvist, Erb and Menges, 2015) the form-finding process is combined with the results of finite element analysis (FEA) using multi-objective optimisation strategies for the creation of digital meshes of elastic threads, which are then reproduced into physical tensile structures using conventional cutting and assembly strategy.

In parallel, the continued development of automated construction tools opens new directions that achieves better material control during the construction process. The design and simulation of custom-made end effector tools for material control move investigation beyond conventional fabrication methods (Iwamoto, 2009), allowing automated procedures that combines fabrication strategies and construction experimentation (Keating and Oxman, 2013). For example, in (Knippers et al., 2015) a custom-made tool mounted on a robotic arm is developed and used for controlling and feeding with thread material. By integrating robotic simulation, form-finding and structural performance analysis the construction of the overall structure can be achieved. In addition, the use of industrial robots, aerial robots or gantries improve the control of the process, allowing the construction of free-form structural systems. Moreover, the integration of simulation mechanisms for form-finding with the end effector tool for tensile mesh structure execution, leads to several advantages as compared to conventional construction techniques, such as the overall control accuracy of materials resulting the accurate repeatability during the fabrication process.



In conclusion, the development of interactive digital design and fabrication techniques that combine real-time form-finding methods, structural optimisation control and fabrication strategies allows a more effective approach in automated tool-path generation (Braumann and Brell-Cokcan, 2012). This, in combination with the integration of custom-made end-effector tool development for material control and the form-finding process, can achieve an accurate repeatability process for the construction of complex tensile mesh structures. Similar works in this direction can be found, for instance in the experimental investigation undertaken in (Wendy and Antoine, 2016), where semi-autonomous wall-based robots are developed for the weaving of a small installation with carbon threads. The direct control between the automated toolpath generation and the material techniques allows the development of innovative fabrication strategies with new materials and complex shapes.

Suggested Methodology

The current research study focuses on the feedback loop communication of form-finding, structural optimisation and tensile analysis with the combination of robotic fabrication principles, which aims towards an automated process. This achieves the development and static behaviour analysis of innovative shapes, as well as their fabrication through precise robotic control. Specifically, a parametrically controlled algorithm is developed that can be used for both, the optimisation and the fabrication of complex elastic tensile structures. In this way, an automated method to control the form-finding process of the elastic tensile shapes and to generate the robotic tool-path through a custom-made end-effector can be achieved. Thus, the automation might respond to the fabrication of any complex system with high accuracy. Important parameters and criteria of optimization control include specific material characteristics, in this case elasticity and diameter, additive weaving technique applied as well as robotic setup and end-effector limitations.

The parametric design environment of Grasshopper, a plug-in for 3D modelling software Rhino, is used for algorithmic development. In this environment, the formulation of 3D input surface and the application of the initial weaving pattern, which in turn defines the final robotic tool-path, is conducted. The physics-based software Kangaroo (Piker, 2013), a plug-in for Grasshopper is applied for the process of form-finding. Within this framework, the thread tensile equilibrium of elastic mesh system, which occurs between the material pretension and tensile strength is taken into account in order to prevent the formation of high sag threads geometry. By using spring behaviour (Kilian and Ochsendorf, 2005) the relaxation of threads is initially simulated, based on the mathematical equation $K = (A \cdot E) / L$, where K is the spring stiffness, A is the cross-sectional area, E is the (tensile) elastic modulus of the rubber (Polyurethane Elastomer) thread (0.02 GPa), and L is the length of the thread. The static equation is used for non-linear mesh behaviour simulation, in which pretension forces are applied on threads leading to grid structure overall deformation and hence its stabilisation (Figure 1). In parallel, results of form-finding are evaluated and correlated with the results obtained by using the general-purpose civil-engineering software CSI SAP2000.

In order to overcome problems due to the complexity of the process, which includes form-finding and specific weaving technique based on the end-effector tool as well as material limitations, a MOGA analysis process (Deb, 2002) is introduced and developed as a feedback loop workflow. The analysis process controls the material section and the prestress behaviour (L/D factor) and considers the robotic setup and the end-effector parameters such as the dimension of nodes, pretension accuracy and positioning. This leads to results influenced by material tensile strength (5MPa) and end-effector tool limitations. The overall process achieves a large number of best solutions to be

generated that are projected on the Pareto front graph. This allows the selection of desirable ones based on their static behaviour by prioritising structural performance and on their geometry by prioritising shape deformation.

In addition to the automated fabrication algorithm (Figure 2) and in order to evaluate the results of digital form-finding and structural optimization with robotic fabrication, a custom-made end effector tool for a small-scale physical prototype is developed. As a consequence, fabrication constraints, which allows an automated mesh weaving process through the working area of an industrial robotic arm ABB IRB2600 with an IRC5 controller, are also used to evaluate the method introduced in this paper. This allows digital to physical experimentation of the initial weaving pattern of the nodes and threads (Kontovourkis and Tryfonos, 2015) in a feedback loop communication.

Initial Pattern Configuration

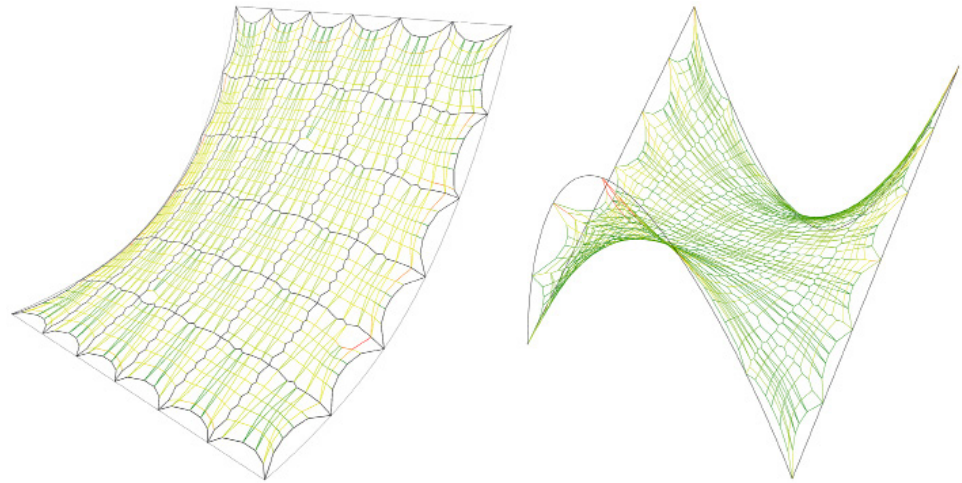
In previous investigations, the research has explored possible weaving patterns that would achieve an automated robotic control (Kontovourkis and Tryfonos, 2015). This has been focused on the capability of the algorithm to control automatically the form-finding and fabrication through tool-path generation. Towards this direction, the research has developed a weaving algorithm to explore eight different input categories with different Gaussian curvatures. Two input lines A and B at a distance (y) are used for the geometrical development and the determination of each elastic mesh. In parallel, eight surface variations for each category of results are achieved by using the two combined curves on which three control points (start, middle and end) in z-axis are modified. The categories are developed based on 1x1 YZ coordinate polygon system, allowing the adaptability in any shape. The correlation of the initial Gaussian curvature (K_s) (Table 1) with the final mesh Gaussian curvature (K_f) values allows the behaviour investigation of the suggested elastic mesh weaving algorithm. The nine interior points for the measurement of the initial and final Gaussian curvature are shown in Figure 3.

Weaving pattern development algorithm

The physical behaviour of every mesh variation in each category and hence the behaviour of the rubber material in each case are tested through the suggested weaving algorithm, together with the sequence of nodes and evolution of robotic toolpath generation. In addition, the size of the surface, the weaving pattern density, the space (y) that is the distance between curves defining the surface, and the value (x) that is the distance of start to end point of each curve including surface subdivision, are determined by parameters controlling the initial geometry. Moreover, the surface subdivision (div) in x and y-direction influences the pattern density. This can be described in details, firstly, by dividing the two lines in corresponding nodes that are connected in one direction based on the parameter (N), for instance in the following sequence, A3, B3, B5, A5, A7, B7, B9, A9, A11 and B11, which create springs 1-9 (Figure 4). Then, the process of weaving continues in the other directions, intersecting and dividing existing springs into two new segments, leading to the creation of spring between two nodes. Also, a movement of nodes by 25-75% of the neighbouring points can be allowed. The connecting nodes to the adjacent units or to the anchor points leading are represented by remaining points on A, B, C and D (Figure 4).

Form-Finding Simulation

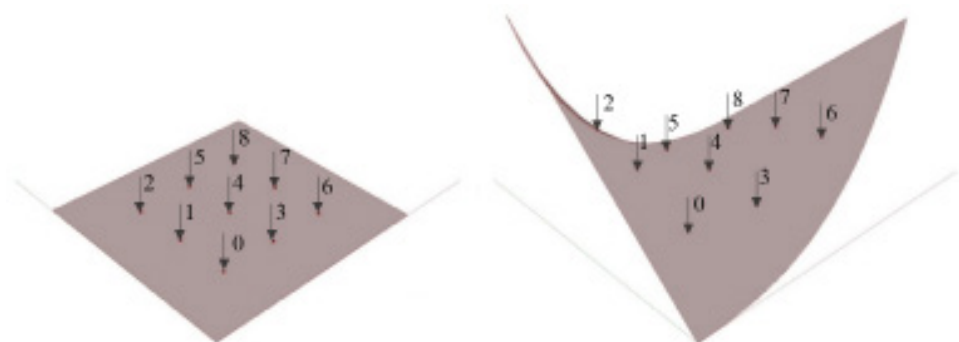
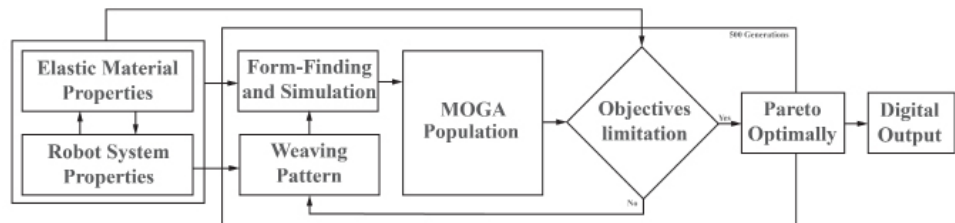
Preliminary physical and digital experiments (Kontovourkis and Tryfonos, 2016) have been used to

**Figure 1.**

Weaving pattern of real scale case-studies after form-finding.
Left B.8 and Right F.8

Figure 2.

The automated robotically driven optimisation workflow in the form of a diagram

**Figure 3.**

Measuring points of the Gaussian curvature

Categories		A		B		C		D	
Curves		A	B	A	B	A	B	A	B
C (m)	Start	0	0	0	0	0	0	0	0
	Mid.	0-0.7	0-0.7	0-0.1	0-0.1	0	0-0.1	0	0-0.7
	End	0	0	0-0.8	0-0.8	0	0-0.8	0	0
Black = A curve Red = B curve									
(-)Ks	0	0	0	0	0	0.15	0.85	1.24	1.77
	0	0	0	0	0	0.09	0.6	1.09	0.75
	0	0	0	0	0	0.05	0.33	0.66	0.30
Categories		E		F		G		H	
Curves		Curves		A	B	A	B	A	B
C (m)	Start	0	0	0-0.8	0	0	0-0.8	0	0
	Mid.	0	0-0.7	0	0-0.8	0-0.1	0-0.1	0.1	0.1-0.8
	End	0	0-0.8	0-0.8	0	0-0.8	0	0.8	0
Black = A curve Red = B curve									
(-)Ks	1.46	0.44	0.05	2.79	0	2.79	1.46	1.92	1.32
	0.81	0.24	0.03	12.68	0	12.68	2.01	3.02	2.01
	0.44	0.14	0.02	2.79	0	2.79	1.32	1.92	1.46

Table 1.

The eight categories and their initial surface Gaussian curvature

determine the material deformation and the tensile forces behaviour applied in the elastic thread. The prestress is described by the thread length and the initial point distance (L/D) and is set at the lower value of 70% for maximum deformation and a maximum value of 100% without deformation. The robotic end-effector capability to apply accurately holding force is used to calculate thread values that occur during prestress and node creation. In order to avoid thread sags in the whole structure, the (L/D) factor is introduced and changed to set the prestress values. Thus, to additionally investigate the node connectivity of the tensile stress behaviour, the anchorages-nodes can be moved from 25-75% affecting the mesh typology and curvature.

As it has been mentioned, the Kangaroo plug-in for Grasshopper is used for simulation and specifically through the particle-spring behaviour modelling approach. At the same time, verification of the results is achieved through the use of SAP2000 software. In order to achieve this, properties of applied material include high tensile strength ($F_{st} = 5\text{Mpa}$) and yield stress ($F_y = 3\text{MPa}$) compared to the elastic module ($E = 2\text{Mpa}$) as well as Poisson's ratio of 0.5. In addition, all material characteristics are used as tendons inputs and the threads are modelled as cables with diameter 0.8mm with deformation prestress and self-weight of $\rho = 0.93\text{ Mg/m}^3$ (Ashby, 2011). Also, the node mass, which is generated by the end-effector tool is calculated as point load with value 0.012985N. The results of SAP2000 nonlinear analysis and the results derived from Kangaroo form-finding process are almost similar with minimum deviations, proving the effectiveness of the process. In addition, the algorithm allows changes in regard to the input thread diameter range from 0.8mm to 20mm as well as adjustment based on external loads, showing future potential for alternative selection of elastic thread diameter that in turn will lead to end-effector modifications for new material control.

Optimisation and Static Analysis

Results of multi-objective optimisation process using the Octopus optimisation engine (Vierlinger and Bollinger, 2014) show a range of acceptable fabrication solutions. Alternation of results are obtained based on changes of anchorage range from 25%-75% and length factor range from L/D 70 - 100%, associated with the tensile stress, the amount of material used and the total deformation material. In addition, material tensile strength limitation of the end-effector tool $F_a = (F_{st} \cdot A) / (S \cdot F)$ (A =section area, $S \cdot F$ = safety factor = 1.35) (Stranghöner and Uhlemann, 2016) is taken into account during evaluation and selection of optimum solutions using the Pareto front (Pareto optimality). This shows that threads of 0.8Ø can be controlled by the suggested end-effector tool. Also, experimentation with YZ scale at 0.7x0.7m due to the limits of the working area of an industrial robotic arm ABB IRB2600 can be conducted.

The process involves 500 generations, each one with a population of 100 solutions, which are evaluated based on the decrease of the average tensile force, the reduction of material deformation under external load and the total length of the deformed elastic material. The deformation of the elastic material, the length amount of material required, the pretension and the curvature are used as objectives to evaluate the static performance and constructability of structure. Optimum results obtained are selected based on their static behaviour and on their geometrical configuration (Kontovourkis and Tryfonos, 2018), firstly by evaluating tension and thread deformation changes and secondly by evaluating curvature changes respectively.

An example of best trade-offs results for the case (F8) for generation 0,50,100,250 and 500 is shown in Figure 5. The two axes of graph describe the average of the tensile stress and the length of the deformed thread, wherein the 500th generation the best Pareto curve appears. The solu-

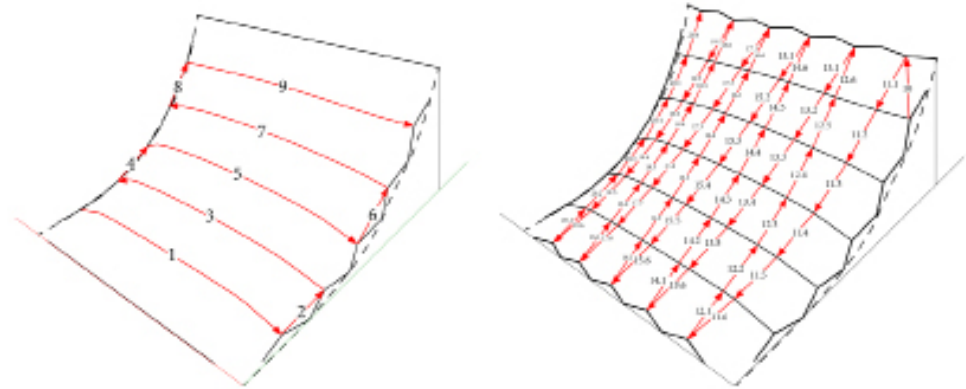


Figure 4.
Elastic threads of the
structure in wave
sequence

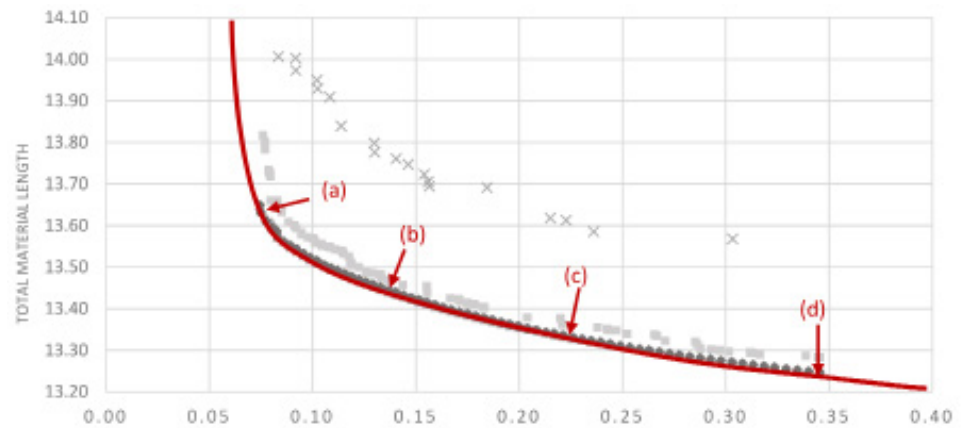


Figure 5.
Case study F8 opti-
mum results.

SOLUTION	a	b	c	d
L/D (%)	89.50%	83.90%	79.30%	70.10%
Average Tension (N)	0.075	0.135	0.196	0.344
Total Material Used (m)	8.719	8.133	7.688	6.798
Total material deformation (m)	0.345	0.686	1.012	1.725
Average Final Curvature -(Kf)	9.491	9.858	10.087	10.348
$K = (-Ks) - (Kf)$	-2.832	-3.198	-3.428	-3.689

Table 2.
Results of Case Study
F8

tion (a) with the minimum tensile stress average 0.075N has the higher L/D factor = 89.5% and deformation length material with value 0.345m, with material length 8.719m as well as the lowest curvature change (K)=-2.832, indicating this as geometrically preferable solution. The solution (d) is defined with the maximum tensile stress average 0.344N and the lowest L/D factor = 70.1% as well as the higher deformation length material with value 1.725m and with material length 6.798m, indicating this as an alternative solution for robotic execution. In general, results where systems' average tensile stress is higher can be considered as optimum and preferable in terms of their static performance and at the same time they use less material length, however their maximum average final curvature (k)= -3.689 show that these are less geometrically acceptable since they require higher pretension during robotic fabrication.

For fabrication execution, solutions that are near to the centre of Pareto front are selected. These consists of less material length and hence better static behaviour since are approaching the maximum allowable (L/D) facto and their average tensile stress is the higher (Table 2, solution c). In comparison, solution (b) (Table 2) has lower average tensile stress and higher (L/D) factor, showing this as a solution geometrically acceptable but with fewer curvature changes and hence with less thread deformation.

Results from small to large-scale algorithmic experiments (Kontovourkis and Tryfonos, 2018) show that solutions with higher section diameter and higher average tension have lower material deformation under the influence of loads and hence higher curvature change, considering these as statically adequate. On the other hand, results with higher material deformation, lower average tension and section diameter have lower curvature change, considering these as geometrically appropriate.

End Effector And Tool-Path Development

After multi-objective optimisation results are obtained and selection of the appropriate solutions for fabrication execution is conducted, a step by step material addition simulation is needed for the construction of elastic threads due to the elastic material behaviour and specifically the deformation of the tensile mesh in every node addition process. The redefinition of the tool-path and the robotic manufacturing process occur automatically and is achieved through 51 (Figure 6) weaving sequence (every additional thread and node in the weaving pattern) simulations per unit mesh.

The end-effector tool is responsible for the pretension of the elastic material and the node creation tasks and generally for controlling the weaving pattern development. The tool is operated through an Arduino board that controls the actuator and the other mechanical parts and it has been programmed to directly communicate with the IRC5 controller and synchronise with the tool-path developed through digital simulation. Analytically, two programming tasks are enabled; a. The pretension of the thread that is calculated from the L/D factor based on automated form-finding and optimisation process, and b. The node creation task (Figure 7) that included operations for holding the threads, supplying and moulding the node using a hot-melt adhesive technique.

Figure 8 shows a preliminary investigation on the robotic fabrication of a robotic toolpath controlled by the custom-made end effector tool. In order to achieve high precision during physical fabrication, calibration of the anchor points in the physical and digital model is required. In a future stage, the physical development of a small-scale tensile mesh system will allow verification of the results obtained during the process of automated robotic toolpath generation.

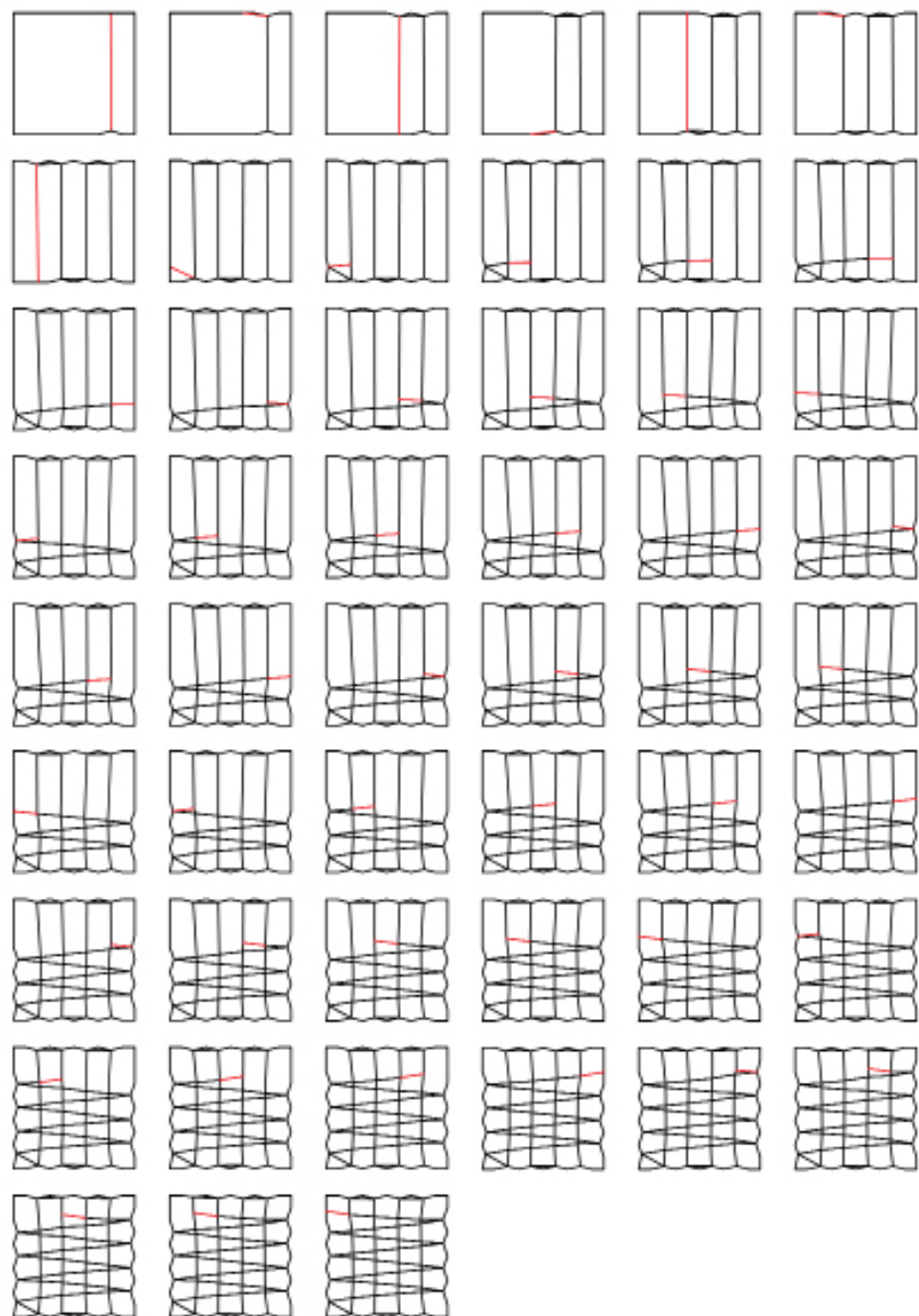


Figure 6.

Weaving sequence
simulation for the
automatic toolpath
generation of one
unit.

Conclusion

This research aims to apply an automated robotically driven procedure for toolpath generation using form-finding, static analysis and MOGA optimization processes for the physical development of elastic tensile mesh structures. The suggested workflow and the involvement of various techniques within a common framework of investigation attempts to examine the viability of the process and hence the effectiveness of the algorithm, to be used towards an automated and integrated procedure that includes design optimization and physical construction. Through the suggested automated procedure that involves repeatability of additive construction task, the accurate control of complex elastic mesh morphologies can be achieved. At the same time, the procedure examines in which extend the users can control the process of design selection and then, the form-finding results. Also, the effectiveness of the weaving technique, which is controlled by the custom made end-effector tool, can be examined. All the above can be accomplished due to the recent developments occur in the area of parametric design and robotic control that offer tools for elastic mesh structure simulation and parallel toolpath generation as well as robotic movement planning and custom-made tool control. The simultaneous use of different tools and platforms extend the ability of users to be actively involved in all parts of the procedure in a holistic manner. Within this framework, designer-user can decide and select the desirable “ready for fabrication design” based on the results obtained during the feedback loop analysis and simulation process.

Feather research will continue towards the physical production of digital results derived from form-finding, simulation and analysis. Also, physical with digital outputs will be compared and evaluated through a series of case studies that will examine possible deviations. The suggested procedure might allow further developments towards the construction of other tensile shapes using similar material behaviour, leading to an ideal and an autonomous holistic construction process of complex, lightweight structures with minimal materials.

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Figure 7.

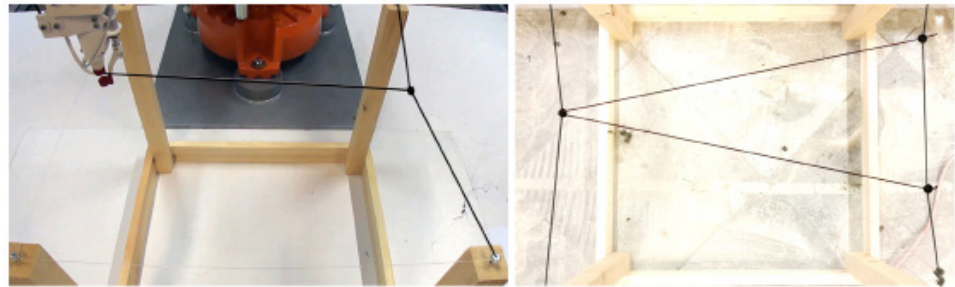


Figure 8.

An example of elastic mesh structure using the suggested end-effector tool.

References

Ahlquist, S., Erb, D. & Menges, A. 2015, "Evolutionary structural and spatial adaptation of topologically differentiated tensile systems", *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 29, no. 04, pp. 393-415.

Ashby, M.F. 2011, "Appendix C - Material Indices" in *Materials Selection in Mechanical Design* (Fourth Edition), ed. M.F. Ashby, Butterworth-Heinemann, Oxford, pp. 559-564.

Bletzinger, K.U. & Ramm, E. 2001, *Structural optimization and form finding of light weight structures*.

Braumann, J. & Brell-Cokcan, S. 2012, "Digital and Physical Tools for Industrial Robots in Architecture: Robotic Interaction and Interfaces", *International Journal of Architectural Computing*, vol. 10, no. 4, pp. 541-554.

Deb, K. 2002, *Multiobjective optimization using evolutionary algorithms*, 1st edn, Wiley, Chichester U.A.

Duro-Royo, J., Mogas-Soldevila, L. & Oxman, N. 2015, "Flow-based fabrication: An integrated computational workflow for design and digital additive manufacturing of multifunctional heterogeneously

structured objects”, *Computer-Aided Design*, vol. 69, pp. 143-154.

Gale, S. & Lewis, W.J. 2016, *Patterning of tensile fabric structures with a discrete element model using dynamic relaxation*.

Gramazio, F. & Kohler, M. 2008, *Digital Materiality in Architecture*, 1st edn, Lars Müller Publishers, Baden.

Iwamoto, L. 2009, *Digital Fabrications: Architectural and Material Techniques*, 1st edn, Princeton Architectural Press, New York.

Keating, S. & Oxman, N. 2013, “Compound fabrication: A multi-functional robotic platform for digital design and fabrication”, *Robotics and Computer-Integrated Manufacturing*, vol. 29, no. 6, pp. 439-448.

Kilian, A. & Ochsendorf, J. 2005, “Particle-Spring Systems for Structural Form Finding”, *Journal of the International Association for Shell and Spatial Structures (J. IASS)*, vol. 46, no. 148, pp. 77-84.

Knippers, J., La Magna, R., Menges, A., Reichert, S., Schwinn, T. & Waimer, F. 2015, “ICD/ITKE Research Pavilion 2012: Coreless Filament Winding Based on the Morphological Principles of an Arthropod Exoskeleton”, *Architectural Design*, vol. 85, no. 5, pp. 48-53.

Kontovourkis, O. & Tryfonos, G. 2018, “An integrated robotically-driven workflow for the development of elastic tensile structures in various scales”, *SUSTAINABLE COMPUTATIONAL WORKFLOWS: Computational Design and Fabrication towards Sustainable Products and Processes - 6th eCAADe Regional International Symposium 2018*, ed. O. Kontovourkis, eCAADe, Nicosia, Cyprus, 24th-25th May 2018.

Kontovourkis, O. & Tryfonos, G. 2016, “Design optimization and robotic fabrication of tensile mesh structures: The development and simulation of a custom-made end-effector tool”, *International Journal of Architectural Computing*, vol. 14, no. 4, pp. 333-348.

Kontovourkis, O. & Tryfonos, G. 2015, “An additive robotic fabrication methodology for tensile mesh structures development”, *IASS2015 Annual International Symposium on Future Visions*, ed. P. Huybers, KIVI, Amsterdam, 17-20 August.

Otto, F., Rasch, B. & Schanz, S. 2006, *Frei Otto, Bodo Rasch: finding form : towards an architecture of the minimal*, 3rd edn, Axel Menges, Fellbach, Germany.

Piker, D. 2013, “Kangaroo: Form Finding with Computational Physics”, *Architectural Design*, vol. 83, no. 2, pp. 136-137.

Stranghöner, N. & Uhlemann, J. 2016, *Prospect for European Guidance for the Structural Design of Tensile Membrane Structures: Support to the implementation, harmonization and further development of the Eurocodes*, Publications Office of the European Union, Luxembourg.

Vierlinger, R. & Bollinger, K. 2014, “Accommodating Change in Parametric Design”, *ACADIA 14: Design Agency [Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)]*, eds. D. Gerber, A. Huang & J. Sanchez, ACADIA, Riverside Archi-



tectural Press, Los Angeles, California, US, 23-25 October 2014, pp. 609.

Wendy, W., F. & Antoine, P. 2016, Digital property : open-source architecture, 1st edn, John Wiley & Sons Ltd, Chichester, West Sussex, UK.

Premises For A Theory Of Architectural Intelligence; A Discourse About Relevance

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Premises For A Theory Of Architectural Intelligence; A Discourse About Relevance

Andreea Movila

“Architects are never good at explaining why what are they do matters”
(Alan Penn)

Abstract

The paper underpin the notion of Architectural Intelligence, understood as a category of “design intelligence” oriented not only to the built gesture but to the entire mission of the architect.

The first part of the study situates the intelligence properly within the structures of mental organization and then the relationship between the architectural intelligence (cumulus of specific mental abilities) and the architectural thinking (an action, the mental manipulation of the information) is analysed. The premises for an Architectural Intelligence Theory are given by the context of the Theory of Multiple Intelligences developed by the psychologist Howard Gardner that claims that there are several types of intelligence and not a single general one (g factor). Following Howard’s criterias of identifying an intelligence, I have documented the inclusion of Design Intelligence in the realm of the Theory and developed the connection with Architectural Intelligence as an associated construct.

Architect’s relationship with the world has been under constantly changing throughout history and the question the paper focuses on is how we can still remain relevant today in this world of fantastic changes.

Reflections On The Context

The relationship of the architect with the world has always been changing over time, still an active historical calibration match. The accounts with the society until the 4th century were very diffused - the architect serving mainly superior courts, the Gods and the power - condition that remained relatively constant until the 19th century as the beneficiaries being the church, institutions of power or the aristocracy while the chapter of middle class the dwelling has been written alone without the architect. The mission of the built gesture spoke in particular about the need for self-referential representation and "in this sense, architecture is used to support supremacy through symbolic capital and symbolic domination" (Bourdieu, 1986). Reverence for the architects of the cathedrals dominated public perception until the proximity of the First Industrial Revolution, when the prodigious changes imposed a major reconsideration within the profession so that the architects caught the middle class attention. In this socio-economic, promising and fertile realm of ideas, the most generous architectural utopias were born.

As a result, we were dealing with a radical transformation of architectural thinking that results in a new understanding of the significance of architecture. Through this shaking of conscience, the architects were calling themselves heroes, a position which seems to be soon lost after the intransigent achievements of modern rationalism denounced an disincarnated vision - for the man, outside himself - that was meant to respond to the needs of a suddenly urbanized population. Neil Lynch also notes that if the twentieth century started in an effervescent note of optimism with visions of revolutionary utopias, is concluded in reflection - "It started with the slogan" Towards a New Architecture "and ended with << Rethinking Architecture >> "

After the "modern crisis" (Husserl) the trend today in the field is now heading to "non-places" (Marc Auge) - airports, abandoned spaces, interstitial spaces, parking spaces, passages, incalculable, strips, undefined realms. The new carefulness in approaching the man is also observed in the trend of architectural awards that no longer appreciate the "need for representation" but attempts to demonstrate the architect's willingness to reveal also the other dimensions of his definition: social catalyst, educator etc.

The mission of today's gestures can be seen through Juhani Pallasmaa's eyes in *The Thinking Hand* (Pallasmaa, 2009), which notes that architecture has provided us with "icons" through which we can understand ourselves, mediating also between the world and man and providing a horizon for understanding the existential condition of being. Instead of participating in the accelerated process of experiencing the world that finds itself today in a very complex dynamic, it should stop time, slow the world's experience and defend us from the excess of "over-communication" (Neil Leach) and noise, by keeping the natural slowness of things. "In relation to the ever-dynamic context, the timeless mission of architecture," reckon the architect „is to create existential metaphors of body and existence that concretize and structure our presence in the world. Architecture reflects, materializes and immortalizes real-life ideas and images. Buildings and cities help us to structure, understand and memorize the amorphous flow of reality, and ultimately to recognize and remember who we are. Architecture helps us perceive and understand the dialectics of permanence and change, find our place in the world, and position ourselves in the continuum of culture and time."

Even today's utopias are much less radical and ironically, more pragmatic and real: technology, robotics, generating algorithms, sustainability or ecology. "The action is the form" (Keller Easterling) reflects how the new architectural utopias forgot about architectural forms because we are aware



that dreams can become alive very easily today, and bet on actions and strategies that become the new paradigm of the field: the architecture of information, and us, architects of information.

Premises and Prerequisites

“Architecture is the great book of humanity, the main expression of man in his various stages of development, either as strength or as intelligence.”
(Victor Hugo - extract from *Notre Dame de Paris*)

Within this framework of historical attunements that send us - as Victor Hugo notices - back to the primary significance of architecture, we are going to open the discourse on the notion of architectural intelligence that is intended to be addressed furtherly.

A recent work by Molly Wright Steenson “Architectural Intelligence, How Designers and Architects created the Digital Landscape” (Steenson, 2017) exploring the work of four architects between the 1960s and 1970s was the one that drew my attention to the notion of Architectural Intelligence. The book did not analyze the concept of “architectural intelligence” per se, but rather of “architecture of information”, for which my approach endeavour a deeper understanding of the first concept. The difference between this two notions is fundamental. “Architecture of Information” that programmers (“software developers”) operates with, describe the ability to manipulate and organize the information in a hierarchical way oriented towards a finality. Richard Saul Wurman at the AIA Conference in Philadelphia with the title: “The Architecture of Information” stated that architects know that to make a habitable and usable city we need more than beautiful buildings that look good. We need information: information about space, information that helps people articulate their needs and respond to change. This is the “Architecture of Information” (Richard Saul Wurman, 1976).

Our study will attempt to outline a theory of architectural intelligence, its deeper meaning discussing the relevance of this dimension throughout history as well as its present requisite starting from Carl Elefante (AIA President 2018) assertion that “Architecture is experiencing a Relevance Revolution now”. In an interview for Thought Economic (The Role of the Architecture in Humanity’s History, June 2012), at the question interrogating what are the key challenges and opportunities facing architecture today, Mohsen Mostafavi responded: “I think one of the key challenges is to makes architecture more relevant. This is very tough as we live in a cultural environment where the value of architecture has been diminished. The architect believes that this is in many ways a cultural issue. He also believes that we live in a particular moment in which we are responsible for describing what is contemporary in the practice of architecture.”

How can we be / remain relevant in the context of a speeding world, when the boundaries of the field dissipate in other fields under our eyes - this is the question that this study will attempt to answer.

Today architecture has to do with the great social needs of a large percentage of the world’s population and it is an enormous but also a distinct chance in the history of architecture that we can design for 90% and not just for 10% of world population. If architecture is a service, we need to understand how to serve meaningfully.

About The Notion Of Intelligence And The Connotations Index

No subject in psychology has caused more intense public controversy than the study of human intelligence. In the recent years there has been an increased interest in the interdisciplinary study of cognitive sciences, neuroscience and architecture. Starting with the last years of the nineteenth century, different meanings of the term “intelligence” have begun to be considered and studied, and we can assert that even today it is still imprecisely located between the di-vergent perceptual cones. For Pei Wang (Wang, 1995), it seems that it is too early to define intelligence and that after decades of study, we still do not know much about this, and for A.R. Jensen many dimensions are still unknown about intelligence and many will remain out of human perception for a long time. He also points out that the term has been used in so many different ways that he risks losing its scientific usefulness. “Despite a long history of research and de-bate, there is still no standard definition of intelligence.” (Jensen, 1982).

The term “intelligence” derives from the Latin nouns *intelligentia* or *intellectus*, which in turn comes from *intelligere* which decline understanding and percep-tual capacities.

There are a number of definitions for understanding this notion. Among the ini-tiatives, the Main-stream Science on Intelligence Editorial:An Editorial With 52 Signatories, originally published in the Wall Street Journal in 1994 and signed by over 52 researchers tried to obtain a certain consensus in terms of notion un-derstanding, but hardly succeeded. Essentially, as (R. J. Sternberg, 1998) was to say, “Looking at things closely, there seems to be definitions of intelligence as many experts are called upon to define”

In the following we attempted to index as many definitions as possible in order to capture a wider picture that will support the subsequent definition of Architec-tural Intelligence and will lead us to some observations.

Several theories of intelligence populated the field of the discourse during time. The theories of intelligence, as is the case with most scientific theories, have evolved through a variety of models.

The four basic categories to be considered are:

- Psychometric theories (intelligence can be measured by psychometric means, Robert Sternberg);
- Cognitive theories, which are concerned with the processes through which the mind works;
- Contextual theories, a combined approach that studies the interaction between the environment and mental processes;
- Biological theories that take into account the neural bases of intelligence.

The Multiple Intelligence Theory developed by Howard Gardner will be mostly reported as a reference in our research and it is based on the idea that people have different styles and cognitive abilities. Human competencies, such as diverse capacities, talents, mental abilities, have been divided into several types of intelligence: linguistic, logical-mathematical, spatial, musical, kinesthetic, interpersonal (for the sense of social relations) and intrapersonal (for self-representation). Other approaches consider that “Intelligence is a computational capacity, a capacity to process a certain kind of information - which is found in human biology and human psychology, so the bio-psychological structure of intelligence must not be lost, while a field or a discipline is a sociological structure (Piaget, 2008). For him any psychological explanation ends sooner or later by relying on biology or logic, so we must consider properly this dual nature of intelligence in our study. As a

Premises for a theory of architectural intelligence; a discourse about relevance

Figure 1.

80 definitions of
intelligence that are
presented by their
keywords.

AUTHOR	KEYWORDS from the definition
DEOnline AllWords Dictionary, 2006 The American Heritage Dictionary, Ed.IV American Psychological Association Cambridge Advance Learner's Dictionary Linda S. Gottfredson, Mainstream Science on Intelligence Columbia Encyclopedia, Ed.VI Random House Unabridged Dictionary Longman Dictionary of Contemporary English Merriam-Webster Online Dictionary Compact Oxford English Dictionary World Book Encyclopedia Wikipedia, Engleza Wikipedia, Română Word Central Student Dictionary Wordnet Wordsmyth Dictionary C. Constantinescu, 2007 Paul Popescu - Neveanu John Mc Carthy și Patrick J. Hayes, 1969 Jean Piaget, 1967 Binet-Simpson, 1905 N. V. Findler, 1979 Alfred Binet, 1916 David Wechsler, 1944 Lloyd Humphreys, 1979 Howard Gardner, 1993 Linda Gottfredson, 1998 Sternberg & Salter, 1982 Reuven Feuerstein, 2002 S. Legg & M. Hutter, 2007 Alexander Wissner-Gross, 2016 Anne Anastasi, 1992 Alfred Binet și Th. Simon, 1905 Mike Anderson, 2006 Walter V. Bingham, 1937 Edwing G. Boring, 1923 S. S. Colvin, 2000 J. P. Das W. F. Dearborn, 2000 Jame. Drever, 1952 F. N. Freeman, 2000 Howard Gardner, 1993 N. E. Haggerty, 2000 V. A. C. Henmon, 1921 Richard. J. Herrnstein și Charles Murray, 1996 Renato Sabbatin Lloyd G. Humphreys, 1979 J. Huarte R. Pinter J. Peterson D. K. Simonton, 2003 R. E. Snow, 2004 Robert. J. Sternberg, 2000 L. M. Terman, 2000 L. L. Thurstone David Wechsler, 1958 H. Woodrow, 2000 Richard. M. Yerkes and A. W. Yerkes, 1920 R. W. Young, 2000 James S. Albus, 1991 David Fogel, 1995 B. Goertzel, 2006 R. R. Gudwin John Albert Horst, 2002 Ray. Kurzweil, 2000 D. Lenat și E. Feigenbaum Shane Legg și Marcus Hutter, 2006 Hassan. Masum, 2002 John. McCarthy, 2004 Marvin Minsky, 1986 Hideyuki Nakashima, 1999 Allen Newell și Herbert A. Simon, 1976 Roger Schank, 1991 K. Warwick, 2004 Peter Voss, 2005 S. Legg și M. Hutter Max Tegmark, 2017	-understand / understand the essence / solve problems -solve problems / adapt to new situations / memory / knowledge, reasoning -knowledge / apply knowledge -understand the complexity of ideas / adaptation to the environment / learning from experience -to teach, to understand -to think, to plan / solve problems / to think abstract / to learn from experience / to capture senses -learning, reasoning, understanding meaning -to teach, to understand -learning, understanding / manipulating the environment / using reason / abstract thinking -apply knowledge -adaptation to the environment -facilities such as rationalization, planning, problem solving, language / abstract thinking -to discover relationships / solve problems -to learn / understand / deal with problems -to understand / capitalize on the experience -understand -the data manipulation capacity -process, skill, attribute -model appropriate to the world / information-procure operations / follow goals -organization / Adaptation / Troubleshooting -to understand, to judge, to reason -approach to new situations / reason / creation of connections / understanding / recognition of truth -good sense / adaptation / self-critical -higher efficiency -operational information / conceptual abilities -solution issues -computational / encoded capacity in a symbol system / bio-psychological structure -cognitive complexity -goal-oriented behavior -adapting to changing requirements -reaching goals -a force -composition of functions, abilities for survival -knowledge, logic, reasoning, judgment / good sense / adaptability -problem solving / reason / cognition -resolving new issues -intelligence -adaptation to the environment -structuring behavior toward purpose -to learn from experience -conversion to a goal -a series of capabilities (flexibility, imagination, speed) -creation of culture -feeling, perception, association / memory, imagination, - judgment, reasoning -knowledge -cognitive ability -combination of mental processes / adaptation to the environment -processing information -the learning capacity -adapt to new situations -biological behavior with effect in behavior -cognitive skills to adapt to the environment -termine the internal and external environment -the ability to succeed, to achieve goals / to learn from experience / to work with abstract concepts -operated with abstract thinking -abstraction capacity -to think rationally / act deliberately -capacity to acquire capabilities -full assembly of functions -this ordering capacity of thinking -proper action towards success -adaptive / touch system objectives -setting objectives -adapt to different environments / achieve success -objection -setting objectives -finding solutions -reach objectives -face different tasks -computer part in the ability to reach objectives -to solve problems -processing information -adapting to different environments and changing goals -to become better in time -mental capacity / success -competence for acquiring knowledge / self-directed learning -capacity to achieve goals -do complex "tasks"

last observation, attention should be paid to the relationship between intelligence (- as an association of specific mental abilities), thinking (- the action of mental manipulation of information) and architectural knowledge.

“Design Intelligence”(D.I.) and the Placement inside of Multiple Intelligence Theory by Howard Gardner

“What makes the human -human is design.
What we design - ourselves.
A history of continuously designing.”

In recent years, the concept of “Design Intelligence” has gained much attention in scientific literature, being seen as the instrument for solving problems in all sectors of human activities and besides Architecture in areas such as Product Design, Information Technology, Business, Education, Medicine etc.

Tony Fry in “On Design Intelligence” (Fry, 2015) and Anita Cross in “Design in-telligence: the use of codes and language systems in design” (Cross, 1986) wrote about this frame concept and concluded the theoretical incursion expressing the hope that “design” will be recognised as a distinct full form of human intelligence, and not merely an eclectic use of knowledge and skills acquired in other fields of activity (Cross, 1986, p.18). This premise is also shared by the present study, which seeks to prove that this intelligence is self-contained as part of the inherent nature of the human being, translating the “demiurgic” tendency of man, which is genetically programmed to build artefacts, once for survival reasons and once to create the existential metaphors of our presence in the world. In other words we “need to constantly destroy us to build us again and again” (Theo Van Doesburg, 1918). On this empirical basis, we will try to build the scientific foundation of the position that “Design Intelligence” should hold a place within the Multiple Intelligence Theory, viewed in this regard as a framework of legitimation and design ability is a form of intelligence (Richard Buchanan, Victor Margolin, 1995) because „Design generally implies the action of intentional intelligence (Gregory, 1987)

In a cumulative sense of translation, “Design” is accepted as: verb- to design, to (pre) conceive, construct, model, draw, prefigure and noun- project, drawing, model, construction, intent, purpose. The basic discussion on “Design Intelligence” starts from the fact that all human activities - whether physiological, professional or cultural etc. involves the ability and activity of “building” that may be building artifacts or the self in relation to the world. What we design - ourselves. A history of continuously designing. There is in man’s nature a demiurgic, almost instinctual tendency / impulse towards creation, perhaps a reflection of our resemblance to divinity - “because we were created on the image and likeness of God” (Genesis 1, 26).

In this regard in Design for the Real World: Human Ecology and Social Change Victor Papanek speaks that .“All men are designers. Everything we do, almost all the time, is design, because design is fundamental to all human activity. Planning and modeling of any act for a desired and predictable purpose is the design process. Any attempt to separate design, to do a stand-alone thing, runs counter to the inherent value of design as the primordial matrix of life. (...) Again: the design of the foundation of human activity. Design is the conscious effort to impose a meaningful order.” Mark Wigley and Beatriz Colomina in the Manifest Work Are We Human? Notes on an Archeology



of Design opinion that “Design is the most humane thing about us. Design is what makes human - a Human “ and that man radiates Design in all directions of his existence. They note that design always claims to serve man, but the essence of his ambition is to “redesign” - in fact, the human. His experience is so intimately linked to the condition of being that we can say that there is no “exterior” in the design world. “Design has become the world.” (Wigley, Colomina, 2016). For Tony Fry, the design / design capability is in itself a form of power that defines the relevance of each individual and then of the society to which it belongs.

In the 1980s and 1990s, with the increasing popularity of artificial intelligence (I.A.), the claim of design intelligence (in this context - Design Intelligence, D.I) gained much greater attention. In fact, it is my attempted to consider Architectural Intelligence as a subset of D.I.

For Tony Fry in On Design Intelligence several relevant directions which demonstrate the distinct position of this intelligence among others are:

- “Design as Element of the Mind”, especially by reverting to the prefiguration ability that he considers the essence of the ability to design;
- The design as involved in the “Existential Fiction of Presence-in-the-world”;
- Design as “Structuring Force of Culture and Key to Expression Registry”;
- Design as an “Artefact Agency”;
- Design as a specific „Hermeneutic Field” because it is a reflective way of “reading the world”, considering that everything we see around the world is due to the act of designing.;
- Design as a „Common Language for Engaging Our Field with Other Fields”, being in its essence an universal language.

Richard Buchanan, Victor Margolin and Nigel Cross in Discovering Design: Explorations in Design Studies (1995) declared that seeing design as a form of intelligence is legitimate. Even if we do not have enough space here to further develop the demonstration, Gardner criteria for identifying an intelligence (Gardner 1983, Kornhaber, Fierros, & Veneema, 2004) should be mentioned:

1. the potential of isolating the dedicated brain region in certain agents and the existence of geniuses, peaks and other exceptional people
2. the presence of a distinct neural structure
3. a distinct trajectory of development
4. evolutionary basis, survival value
5. the susceptibility to coding (symbolic expression)
6. results obtained from psychometric findings.
7. support from experimental psychology;
8. the presence of basic operations

“Architecture” - as a verb and the premise of developing a theory of Architectural Intelligence

What is architecture as a verb? Molly Wright Steenson asks in the preface of her book (Steenson, 2017). It depends on who you ask, she appreciates. The definition of architecture in traditional terms will refer to the practice of constructing buildings of any nature - of any human use. However, the verb is also used by programmers/ software developers and architects of information and for them “architecture” means designing a system that works holistically, hierarchically and organized. The way they boil down to this notion speaks of what architects are doing, essentially about

the complexity of their work. This transgression of significance is a fairly recent phenomenon that has evolved with the development of information systems that involve the creation of intelligent systems, reasoning, adaptation, etc.

As a result of things stated above, our conclusions so far are:

If “design intelligence” is the intelligence of creating “intelligence” then

Architectural intelligence is a category of “design intelligence” oriented not only to the built gesture but to the entire mission of the architect.

In this context, the demonstration will focus on establishing the particularities of architectural intelligence within the design intelligence category both cognitively and biologically. Countless areas involve “design thinking”: “diplomacy design”, “design of social impact”, “biological design” or “design for social justice” etc. that brand themselves as “designers” for “experience,” “interfaces,” “software,” “brand,” or “interaction”. “Design thinking” has become nowadays a dominant model of thinking that affects everything, from politics to education, personal relationships, research, communication and philanthropy, and as noted in *Are we human?* (Colomina, Wigley, 2016) - “Design has become almost dangerously successful”. In this territory, architectural intelligence occupies the most general territory in the sense of being a “hybrid and impure discipline” (Pallasmaa, 2013). In this regard he also draws attention to the fact that, in addition to his traditional dependence on tacit knowledge of construction practices, architecture relies heavily on the theories and discoveries of other areas of research and knowledge, instead of possessing an independent theoretical basis.

For the purpose of this paper we will isolate two of the specific features.

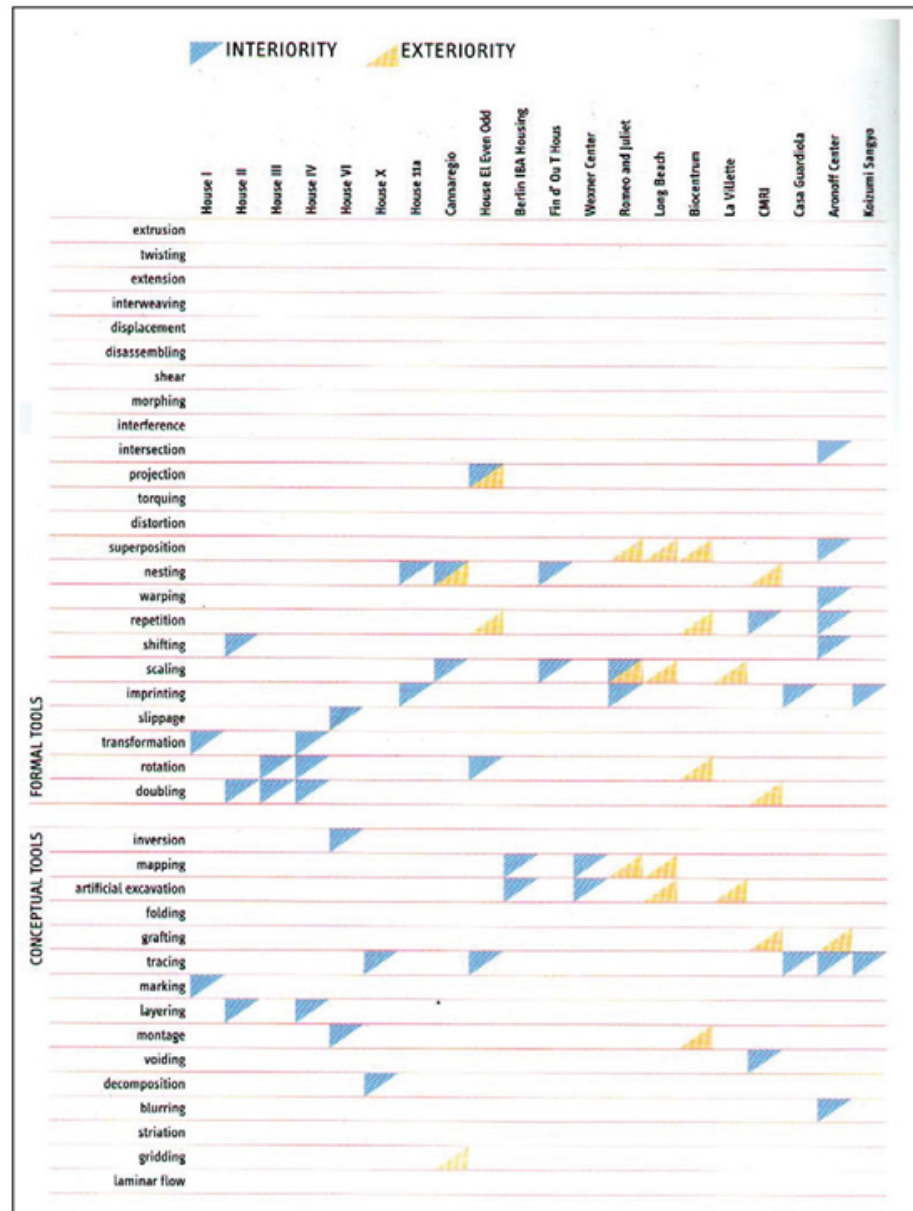
1. Architectural Intelligence involves separate processes and operations of information processing

A research thesis by Turkish architect Kerem Yazgan introduces *Designography in Architecture* as a new field of study that is about designing the design theme and writing the design program over the initial program for a better management of spatial relationships beforehand. This strategy would allow for a better transition between the thinking process and stages of the project.

What could be the distinctive architectural thinking acts in the phases of the design process? Eisenman offers a few possible directions in his book “Diagram Diaries”: twist, extension, interconnection, movement, intersection, disassembly, shear, interference, projection, tracing, marking, mapping, repetition, extrusion, etc. which he calls “formal and conceptual tools” to become operational elements in a design process. Another similar list of different operations involved in the design process is found in his chart below.

The strategy implies the use of different acts as mediators of designing process. Another example are Bernard Tschumi’s design strategies at La Villette Park, reported as “overlapping,” “juxtaposition,” “decomposing,” “distorting,” “fragmenting,” “combining” etc. The thesis argues that architectural intelligence distinctiveness rely on analyzing how the aforementioned actions function in the design process “interiority” and “work-being”.

Eisenman's Table of Tools. (source : Peter Eisenman, Diagram Diaries, London: Thames and Hudson, pp.238-139.)



Architectural Intelligence is supported by biological foundations

Neuroscience of the Architectural Design Process and Neurophenomenology (Neuroscience of the Architectural Experience) are the two directions involved by the study but the first one is now of interest for our study. In 1999, Nancy Kanwisher and her associates published an article in *Neuron Journal* - Elsevier that set the premises for some links between the brain and architecture. She called the place in the brain where this link is made to the area - parahippocampal place (PPA). PPA is defined as the set of all contiguous voxels in the parahippocampal region that showed a more significant reaction during the production and experience of architecture.

The various lobes of the brain provide a biological foundation for the positioning of architectural intelligence. Almost all the occipital lobe behind the brain is dedicated to visual processing, often called visual cortex.

Two other areas in each hemisphere are of interest to architects - the hypothalamus and the thalamus, areas are also under intensive study today, being critical for the recovery of both short and long term memories. The two hippocampus, along with the surrounding cortical tissue, have another interesting function, which is spatial orientation and time navigation(- memory). The brain becomes particularly interesting as we move into the region called the limbic system: two assemblies of modules often called brain power. Some of their components, such as the hypothalamus, the amygdala, the basal ganglia and the pituitary gland participate in various activities such as movement, feeding, but also emotions related to architectural experience. Discovery of mirror neurons found by a group of neurophysiologists working in Parma (di Pellegrino et al 1992, Gallese et al 1996, Rizzolatti & Craighero 2004, Rizzolatti & Sinigaglia 2008) are of interest in this discussion. They found cells that had a surprising extra property that fire not only when an individual perform its preferred action, but also when he observes someone performing a similar action.

Relevant to the architectural thinking and creative process (when we say Eureka! finding a great idea) is the anterior cingulate cortex (ACC), which is considered one of the executive brain centers that focuses on relevance and attention by suppressing irrelevant thoughts. During experiments, the language processing area, the left temporal lobe (Wernicke area), have set the premises of transition to the third dimension of the problem, the semantic problem which will not be approached here. The thesis that Architectural Intelligence is a special form of human intelligence is based on the fact that pre-figurative thinking implies also the manipulation of non-verbal codes of material culture.

Among studies on architects, some test to understand the architect mind were conducted in the early 1950s at the Institute of Personality Assessment and Research (IPAR) at the University of California, Berkeley. Over the course of four weekends in 1958 and 1959, IPAR brought together 40 of the most well-known and important architects of the period among which Richard Neutra, I.M. Pei and Louis Kahn, Eero Saarinen. The findings of IPAR, however flawed, proving that creativity out of bounds for scientific study.

In a philosophical-psychological study, Harry F. Mallgrave linked the findings of neuroscience to the field of architecture in his book *The Architect's Brain: Neuroscience, Creativity, and Architecture*, that speaks of several ways of architectural thinking, in relation to historical periods and thinkers of architecture. As he states:

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Figure 3.

Building construction involves various operations and actions (Source: Arda Duzgunes, 2000, ARCH 251 Building Materials and Components Lecture Notes, Ankara: Middle East Technical University, p. 3.)

SPECIFIC PROCESSES (continued):

○ scratching	○ screeding	○ mixing
○ blending	○ stretching	○ shearing
○ calendering	○ crimping	○ beating
○ electrolyzing	○ vaporizing	○ homogenizing
○ expanding	○ shrink-fitting	○ non-abrasive cutting
○ crushing	○ filtering	○ melting
○ boiling	○ washing	○ heating
○ cooling	○ smelting	○ refining
○ air-blasting	○ freezing	○ compressing
○ pulverizing	○ purifying	○ kiln-drying
○ polymerizing	○ hydrolyzing	○ tanning
○ distilling	○ pickling	○ bleaching
○ oxidizing	○ reducing	○ burning
○ de-toxifying	○ calcifying	○ calcining
○ de-calcifying	○ precipitating	○ vitrifying
○ dressing	○ irradiating	○ crystallizing
○ ironing	○ cycloning	○ binding
○ fixing	○ dissolving	○ ionizing
○ compounding	○ hot forging	○ cold forging
○ quarter-sawing	○ plain sawing	○ boring
○ de-odorizing	○ figuring	○ stapling
○ twisting	○ tightening	○ cracking (petroleum)
○ coupling	○ puddling	○ sluicing
○ polling	○ shaking	○ spiking
○ sinking	○ de-ionizing	○ stoking
○ coiling	○ exploding	○ loading
○ charging	○ tanking	○ boxing
○ canning	○ bottling	○ packing
○ bagging	○ cleaning	○ splining
○ dragging	○ excavating	○ blowing
○ pattern rolling	○ thermo-bonding	○ adhesive bonding
○ abrasive polishing	○ ageing	○ skimming
○ coating	○ scrubbing	○ lubricating
○ de-greasing	○ injecting	○ incubating
○ exhausting	○ tracing	○ macerating
○ submerging	○ melding	○ tapping
○ die-cutting	○ closing	○ cropping
○ solidifying	○ gelling	○ setting
○ steeping	○ mashing	○ aerating
○ sludging	○ reaming	○ honing
○ sharpening	○ beveling	○ chamfering
○ spindle-molding	○ housing	○ routing
○ offsetting	○ tenoning	○ mortising
○ clenching	○ countersinking	○ punching
○ kneading	○ evaporating	○ capping
○ caking	○ caulking	○ sealing
○ rebating	○ channeling	○ dadoing
○ stiffening	○ boasting	○ dessicating
○ clamping	○ wedging	○ cleating
○ straining	○ slumping	○ piercing
○ sponging	○ skinning	○ granulating
○ stacking	○ lapping	○ scarfing
○ bolstering	○ upholstering	○ hanging (wallpaper)

Figure 4.

Bernard Tschumi's design, La Villette Park, New Age Architecture Site



- Human brain: Alberti, Vitruvius and Leonardo
- Enlightened brain: Perrault, Laugier and Le Roy
- Sensational Brain: Burke, Price and Knight
- The transcendental brain: Kant and Schopenhauer
- Brain The animated brain: Schinkel, Bötticher and Semper
- The empathic brain: Vischer, Wölfflin and Göller
- Gestalt Brain: Dynamic field dynamics
- Neurological brain: Hayek, Hebb and Neutra
- The phenomenal brain: Merleau-Ponty, Rasmussen and Pallasmaa

One of the suggestions of this book is that the architect's brain of the nineteenth century - the Renaissance architect for instance - is configured quite differently from the 21st Century architect's brain. The growing interest in architecture neuroscience has already led to the establishment of the Academy of Neuroscience for Architecture (ANFA) in San Diego, California.

These findings are quite recent due to the refining of various brain imaging technologies, such as fMRI, positron emission tomography (PET), electroencephalogram (EEG) and magnetoencephalography (MEG). In fact, the attention paid to these studies set the premises for important breakthroughs that will revolutionize how we think of ourselves as well as approaching neural plasticity issues (that is the capacity of the brain to alter its neural wiring as part of the learning process). Given that nearly 50 percent of neural circuits in the brain are formed after birth, treating education and brain understanding with consideration reflects prodigious opportunities.

Conclusion

"Architecture stands with one leg in a world that's 3,000 years old and another leg in the 21st century. This almost ballet-like stretch makes our profession surprisingly deep. You could say that we're the last profession that has a memory, or the last profession whose roots go back 3,000 years and still demonstrates the relevance of those long roads to-day. Initially, I thought we were actually misplaced to deal with the present, but what we offer the present is memory.")

Rem Koolhaas, (Interview, AIA Convention 2016, www.fastcodesign.com)

This paper endeavoured to establish the premises for a Theory of Architectural Intelligence. Such an approach appears to be relevant today more than ever when the discussion about the Intelligence experience a very large revival nowadays, mirroring the new paradigm of Artificial Intelligence. How can we be/remain relevant today is the question to be addressed in this new dialogue. Architectural Intelligence as a red line going throughout history is a deeper matter of thought, because essentially the history is not as important as the information that transcends the history.

References

Pallasmaa, Juhani, *The Thinking Hand: Existential and Embodied Wisdom in Architecture*, Architectural Digest, 2009

Stenson, Molly Wright, *Architectural Intelligence, How Designers and Architects Created the Digital Landscape*, MIT Press, 2017



Figure 5.

The limbic system
(Illustration by Amjad
Alkoud Source: The
Architect's Brain,
Neuroscience, Cre-
ativity, and Architec-
ture - Harry Francis
Mallgrave)

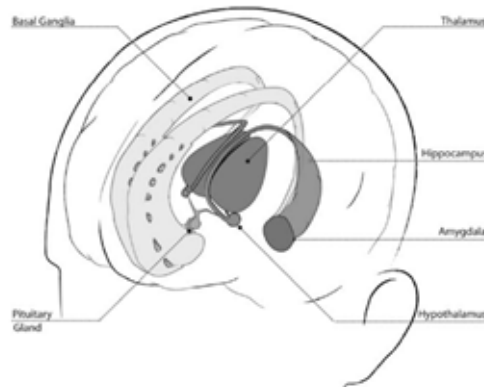


Figure 6.

Lobes of the brain
(Illustration by Amjad
Alkoud Source: The
Architect's Brain,
Neuroscience, Cre-
ativity, and Architec-
ture - Harry Francis
Mallgrave)

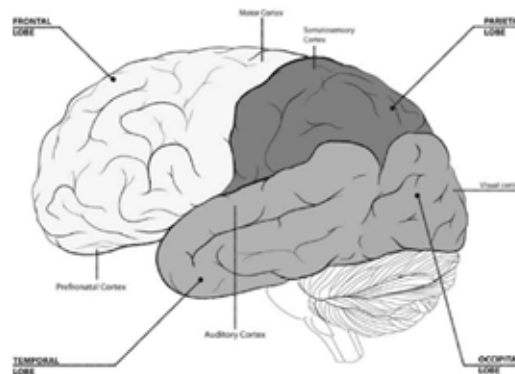
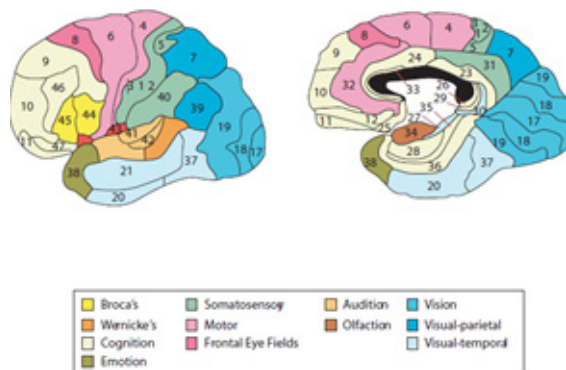


Figure 7.

Brain Landscape:
The Coexistence of
Neuroscience and
Architecture (Eber-
hard 2008, Michael
Arbib, neuroscientist)



Richard Saul Wurman :An American City:The Architecture of Information (Washington, DC:AIA, 1976), I ,4

Wang,Pei, On the Working Denition of Intelligence, Center for Research on Concepts and Cognition, Indiana University 510 North Fess, Bloomington, IN 47408, USA, 1995

Jensen,A. R., Reaction time and psychometric g. li H. J. Eysenck (Ed.),A model for intelligence (pp. 93–102). Berlin: Springer-Verlag,1982

R.J.Sternberg quoted by R.L.Gregory in The Oxford Companion to the Mind. Oxford University Press, Oxford, UK, 1998

Anderson, Mike, Marrying Intelligence and Cognition A Developmental View, January 2004

Piaget, Jean, Psichology of Intelligence, Ed. Cartier, Bucure ti 2008,p7

Fry,Tony, On Design Intelligence, Design Philosophy Papers,VOLUME 3, ISSUE 2,2005, PP 131–144

Papanek,Victor, Design for the real World:Human Ecology and Social Change,Academy Chicago Publishers, USA, 1985, 2009

Chichester,John Wiley, Alan H.Bridges, Design methods in architecture (1984). 256pp.
Buchanan,Richard,Victor Margolin, Discovering Design: Explorations in Design Studies, 1995,The University of Chicago Press

R.L.Grgory, ed.The Oxford Companion to the Mind, Oxford University Press,1987

Mallgrave,Harry Francis, The Architect's Brain, Neuroscience, Creativity, and Architecture, Wiley Blackwell Publication, 2010

Colomina Beatriz,Wigley, Mark Are We Human? Notes on an Archaeology of Design, Lars Müller Publishers, 2016

Yazgan, Kerem, Designography of Architecture, Iulie 2003, MIDDLE EAST TECHNICAL UNIVERSITY

Pallasmaa, Juhani, Harry Francis Mallgrave i Michael Arbib, Philip Tidwell (ed.) Architecture and Neuroscience,Tapio Wirkkala-Rut Bryk Foundation, 2013

Cross,Anita, Design intelligence: the use of codes and language systems in design, Design Studies, 1986, Butterworth & Co (Publishers) Ltd

Intelligence, wikipedia : <https://en.wikipedia.org/wiki/Intelligence>

Rem Koolhaas Interview: <https://www.fastcodesign.com/3060135/rem-koolhaas-architecture-has-a-serious-problem-today>



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From Smart to Cognitive Cities: Intelligence and Urban Utopias

Artemis Psaltoglou

"We are out of reality when we accept the current conditions as constant data and we force humans do machines' labor. We force him to cease being human, trying to perfect an already dead system."

*Takis Ch. Zenetos, Electronic Urbanism
(Kalafati and Papalexopoulos, 2006)*

Abstract

Recent approaches in human intelligence have provided us with a broader understanding about its multiplicity and its dynamic nature. The human capacity to imagine beyond the existing has led to the creation of utopias as a way to fantasize about future societies and future cities. The current article explores how the concept of human intelligence is reflected in urban utopias. More specifically, it focuses on two current urban utopias, which are the predominant urban visions for the digital era: Smart and Cognitive cities. The vision of smart cities, grounded in the intensive use of information and communication technologies (ICT) for the sustainable development of cities, gained a lot of popularity and a wide range of smart city initiatives have been implemented across the world. Apart from the criticism for the technological determinism of smart cities and for endorsing a corporate vision of cities, it is argued that the dominant approach of smart cities consider intelligence as a mainly technological function. Based on advances in cognitive computing, cognitive cities expand the concept of smart cities through the introduction of cognition and learning. The article concludes with some thoughts on intelligence and the function of utopian thinking, and underlines the role of technology as one among many interrelated elements that compose our cities.

From intelligence to utopian thinking

Intelligence is considered a fundamental element of the brain that integrates several cognitive functions such as perception, attention, memory, language. When we refer to humans, the term 'human intelligence' is usually employed, since other forms of intelligence have been also studied, like animal intelligence. There has been a long history of research and debate on how intelligence can be defined and whether there can be a single standard definition for it. In their extensive work, Legg and Hutter present a collection of 70 distinct definitions of intelligence (Legg and Hutter, 2007), assuming that there is no objective sense in which one could be the correct one.

Reasoning, problem solving and learning are considered among the most crucial facets of human intelligence. However, they are not the only ones and many approaches of the previous century, including the intelligence testing (I.Q.) movement, the Piagetian and the information-processing approaches have focused on one view of human intellect. There have been several attempts to provide a more comprehensive description of intelligence and focus precisely on the neglected areas. Howard Gardner suggested the 'theory of multiple intelligences' in which he describes nine distinct types of intelligence, each of which is composed of a number of separate sub capacities: logical-mathematical, linguistic, spatial, musical, kinesthetic, interpersonal, intrapersonal, naturalist and existential. He describes spatial intelligence as the ability "to perceive the visual world accurately, to perform transformations and modifications upon one's initial perceptions, and to be able to re-create aspects of one's visual experience" (Gardner, 2011). According to this theory, each one of these types is related to different parts of the human brain and their distribution varies significantly per person. Emotional intelligence was the last type to be defined by David Goleman who provided novel insights into the brain architecture underlying emotion and rationality (Goleman, 1995).

"Intelligences" are not static; they continuously evolve through practice and learning. They are highly interrelated among them and, at the same time, directly intertwined with the concepts of imagination and creativity; they involve "operations of creating inner environments into which to place echoes of external patterns" (Novak, 1997). The capacity to imagine beyond the present and beyond the existing world is considered one of the driving forces for the evolution of humankind. Harari argues that the ability to imagine things collectively gave Sapiens the ability to cooperate flexibly in large numbers, found cities with thousands of population and, therefore, rule the world (Harari, 2014). In their attempt to make sense of the world that surrounds them, humans are able to envision something that does not exist, transcend the present and fantasize about the future.

The ultimate expression of humans' ability to imagine beyond the existing is utopian thinking; since the very beginning of human thought, humans have been imagining ideal societies and perfect worlds as a way to express their desire for change. However, utopias cannot be seen out of their historical context. In any time period, utopian thinking is derived from the specific socio-political conditions of the era and reflect different approaches to the notion of the "ideal". Both Plato's Republic and Thomas Moore's Utopia, described the ideal society as an instrument of education and ethics. During the Renaissance, utopian thinking expresses the greatness of the city as well as the absolute power of the king. In more contemporary approaches, utopian thinking seems to be a critical tool for questioning the existing status quo



and revealing deficient aspects of existing societies. Another expression of utopian thinking is dystopia, referring to societies that are undesirable and terrifying. Dystopias have been extensively explored in literature and cinema, as a means to underline problematic social and political practices of societies.

This article explores how the concept of human intelligence is reflected in urban utopias. This exploration is based on two axes. On the one hand, considering utopian thinking as the ultimate expression of human intelligence, it briefly presents two contemporary visions of the ideal city for the digital era: Smart and Cognitive cities. Undoubtedly, several approaches can be found in the literature on how digital technologies can be employed in cities, such as the virtual city (Ingram et al., 1996), the digital city (Schuler, 2002), the sentient city (Shepard, 2011). However, it is out of the scope of this article to comparatively present contemporary approaches on urban utopias. Therefore, it focuses on smart cities, as the predominant urban vision that adapts the concept of intelligence in cities, and on cognitive cities as a vision that expands the smart city approach. On the other hand, this article argues that our understanding of human intelligence determines our approach on non-human intelligence, such as city intelligence and artificial intelligence. In this context, it examines how the concept of city intelligence has evolved through these visions.

Smart cities as a new Utopia

Utopian thinking has been particularly interested in cities and has played a central role in the literature on urban planning. It focuses on cities not only in the level of organization and morphology but also in the level of symbolism and representation of social values; from Giovanni Battista Piranesi's engravings glorifying the splendor of Ancient Rome, the visionary work of Étienne-Louis Boullée challenging the limits of construction and the industrial complex designed by Claude-Nicolas Ledoux in Chaux, to Garden Cities by Ebenezer Howard and Le Corbusier's Ville Radieuse. More humanistic approaches that exploit the potential of technology questioning our perception of the urban environment have also been presented during the 20th century, as in the case of Constant Neuenhuys's New Babylon and Electronic Urbanism Takis Ch. Zenetos.

During the last decade, globalization, urbanization and a rapidly increasing growth of Information and Communication Technologies (ICT) have given rise to a new generation of cities, a new Utopia promising to tackle urban challenges in the Information Era: smart cities. Another widely accepted term referring to this generation of cities is intelligent cities (Komninos, 2015). However, it is out of the scope of this article to dig deeper in the conceptual framework of these terms, so they will be used as complementary. Briefly, smart cities emerged as a new paradigm for urban development based on the utilization of human, collective and technological capital towards the enhancement of prosperity in urban agglomerations (Angelidou, 2014).

The global interest on smart cities has exponentially increased during the last fifteen years (Komninos and Mora, 2018), and this does not necessarily imply that smart cities have never existed before. On the contrary, there are scientific approaches demonstrating that ancient Rome was a smart city (de Rita and Häuber, 2015). However, what substantially differentiates ancient cities that probably were smart, is that the contemporary notion of smart cities is

grounded in the intensive use of ICT for the sustainable development of cities.

Today, over half of the world population is online and there is a fast growth of internet penetration worldwide¹. Daily human activity on the internet has led to the production of huge amounts of data. At the same time, integrating and analyzing this data with the enhanced capabilities of ubiquitous and pervasive computing revealed a new horizon of opportunities. In this context, 'smart cities' emerged as a new urban vision capable of addressing these challenges; a new utopia aiming to improve the functioning of cities, enhancing their efficiency, improving their competitiveness, and providing new ways to deal with poverty, social deprivation, and environmental degradation. Since the emergence of the smart city paradigm, a wide range of tools and applications have been developed regarding several aspects of urban life. The technological advancements of the last decades have facilitated the development of applications that use ICTs to improve urban function management in transportation, energy, water, waste but also healthcare and governance; from sensor-based solutions to monitor and increase efficiency in waste management to online reporting platforms and participatory tools for urban governance². We could claim that, considering smart city as a utopia, it has been the first time that reality got so close to such a vision. Not many years ago, the idea that a city could be smart was considered a science fiction and now it is difficult to find a region of the planet where some form of smart city initiative has not been embarked (Almirall et al., 2016). Nevertheless, there has been a tremendous divergence in these approaches in both objective and outcome: from dealing with traffic congestion, parking and energy efficiency issues, to introducing novel governance schemes that support citizen participation. At the same time, despite the wide range of these implementations, the promise for an ideal smart society moved even further away, as new challenges appeared and dark sides of 'smartness' were highlighted.

Smart cities as a new Dystopia

The criticism on smart cities already counts more than a decade. One of the main axes of this critique is related to the technocratic focus on the concept of 'smartness', and therefore, the concept of 'intelligence'. In the notion of smart city, many urban problems are reduced to efficiency problems, problems that can be tackled mainly through the use of ICT (Kitchin, 2013). Assuming there is an automatically positive impact of ICT on cities, smart city solutions combine sensors and data with sophisticated algorithms to minimize costs, optimize functions and maximize

1. <https://wearesocial.com/blog/2018/01/global-digital-report-2018> (Access 25 May 2018).

2. More information regarding smart city applications can be found on ICOS, an open meta-repository of existing applications for smart cities, some of which are open-source. <http://icos.urenio.org/> (Accessed: 19 June 2018).



benefits. Similar to our previous understandings of human intelligence as a set of cognitive functions that can be measured and evaluated through I.Q. tests, smart cities have adopted this view of intelligence in the context of cities. Assuming complex urban phenomena can be dismantled into clearly defined problems, they can be solved or optimized through computation, what is defined as 'solutionism' (Morozov, 2013) or 'instrumental rationality' (Mattern, 2013). As Hill (Hill, 2013) says, smart city thinking "betrays a technocratic view that the city is something we might understand in detail, if only we had enough data – like an engine or a nuclear power station – and thus master it through the brute force of science and engineering."

Another aspect of the criticism on smart cities refers to the subjection of urban development and urban governance to corporate interests of multinational companies. More specifically, since urban problems and solutions are framed in this narrative of complexity and efficiency, public authorities lack the necessary expertise to deal with them, and therefore, high-tech companies become central actors of the smart city vision. So far, the smart city agenda is largely promoted by some of the world's biggest software and hardware companies and this has given rise to a significant concerns regarding the marketization of public services (Hollands, 2008) and the creation of technological lock-ins that bound cities to particular platforms and providers (Kitchin, 2013). At the same time, as data is commonly considered the oil of the digital era, further concerns on data ownership and privacy are still vulnerable points in the smart city debate (Greenfield, 2013).

The smart city movement has also been widely criticized for neglecting its social as well as democratic dimension on the expense of understanding more technological and policy aspects (Chourabi et al., 2012; De Lange and De Waal, 2013). This criticism lies on the idea that smart cities' rhetoric for citizen participation and democratic decision-making is essentially limited since private interests are highly prioritized. Social tensions and conflicts tend to be reproduced and magnified (Graham, 2002) while little space seems to be left for people to do anything other than adjust to the conditions of the smartmentality (Vanolo, 2014). Moreover, solutions tested and implemented in smart city initiatives worldwide entail the danger of deepening inequality by sharpening the digital divide with the exclusion of digitally marginalized groups, the offline populations as they are sometimes called.

More recent approaches of smart city literature recognize the above criticism and acknowledge that technology-driven implementations of smart cities prove inadequate in exploiting the human and social dimension of cities. In turn, they try to reframe the concept of 'smartness' putting citizens in the center and prioritizing citizen engagement in the making of smart city. These approaches are framed under different labels implying that they are improvements of the smart city concept. Among them, there is a call for 'human smart cities', where co-design and co-production of social and technological innovation is supported by the city government (Oliveira and Campolargo, 2015), as well as for 'social smart cities' that focuses on strategies for participatory governance (Effing and Groot, 2016), or even 'smarter cities' (Afzalan, Sanchez and Evans-Cowley, 2017).

However, going back to the concept of human intelligence and utopian thinking as one of its ultimate forms of expression, we could detect an inherent danger in the concept of smart cities. Briefly, smart cities are envisioned as cities of the future that offer a high quality of life for people in terms of welfare, culture and entertainment as well as security and other aspects of everyday life. So, apart from the technological determinism of smart cities, it is assumed

that this future of work, consumption and leisure is a common desire of everyone (Hollands, 2015). In this way, urban visions are increasingly reduced to a single technology-centric vision for the city of tomorrow; the horizon of other possible imaginative approaches is restricted and there seems to be no alternative solutions to the problems of today and tomorrow (Vanolo, 2014). Intelligence and smartness are mainly technological and institutional functions of the smart city whereas individual intelligence seems to remain neglected.

From Smart to Cognitive Cities

Understand the functioning of human brain and intelligence has always been among the ultimate goals of science. Although we still have only a rudimentary understanding of how human brain works, there have been remarkable advances both in cognitive neuroscience and in computer science during the last decades. Cognitive computing, referring to hardware and software that mimics the functioning of human brain, has transformed the way we interact with machines and has opened a whole new world of possibilities. Natural language processing, artificial neural networks and image recognition are among the main technologies in this field. Briefly, cognitive systems are systems capable of sensing, perceiving and responding to changes in their environment, and therefore, adapting to it (Moyser and Uffer, 2016). To achieve this level of computing, cognitive systems have to be (1) adaptive, (2) interactive, (3) iterative and stateful and (4) contextual (Feldman and Reynolds, 2014).

In this context, the concept of “cognitive city” appears as an attempt to expand the limits of smart city and overcome its weaknesses by introducing cognitive theory³ while at the same time builds on learning cities (Larsen, 1999; Longworth, 2006). Initially described by Mostashari (2011), the cognitive city approach underlines the role of learning, memory creation, experience retrieval and adaptability as fundamental processes for coping with current urban challenges (Alonso and Mencar, 2017). These processes are embedded in the city and ICT are leveraged to continuously improve their functioning. As suggested by the theory of connectivism⁴, people do not only learn based on their own experiences but also based on the experiences of others. Similarly, in a cognitive city learning is a process related not only to people but to any system that generate and handle information and is acquired through constant interaction between people and ICT, so that common existing knowledge increases (Siemens, 2005). Institutional learning is also a fundamental pillar of cognitive cities and it reflects the capacity of the city to absorb and produce and

3. Cognitive theory or cognitivism is a theoretical framework in psychology suggesting that individual's knowledge is partly acquired through memory creation based on observing others within the context of social interactions and experiences. Behaviorism, cognitivism, and constructivism are three broad learning theories commonly used in the creation of instructional environments (Siemens, 2005).

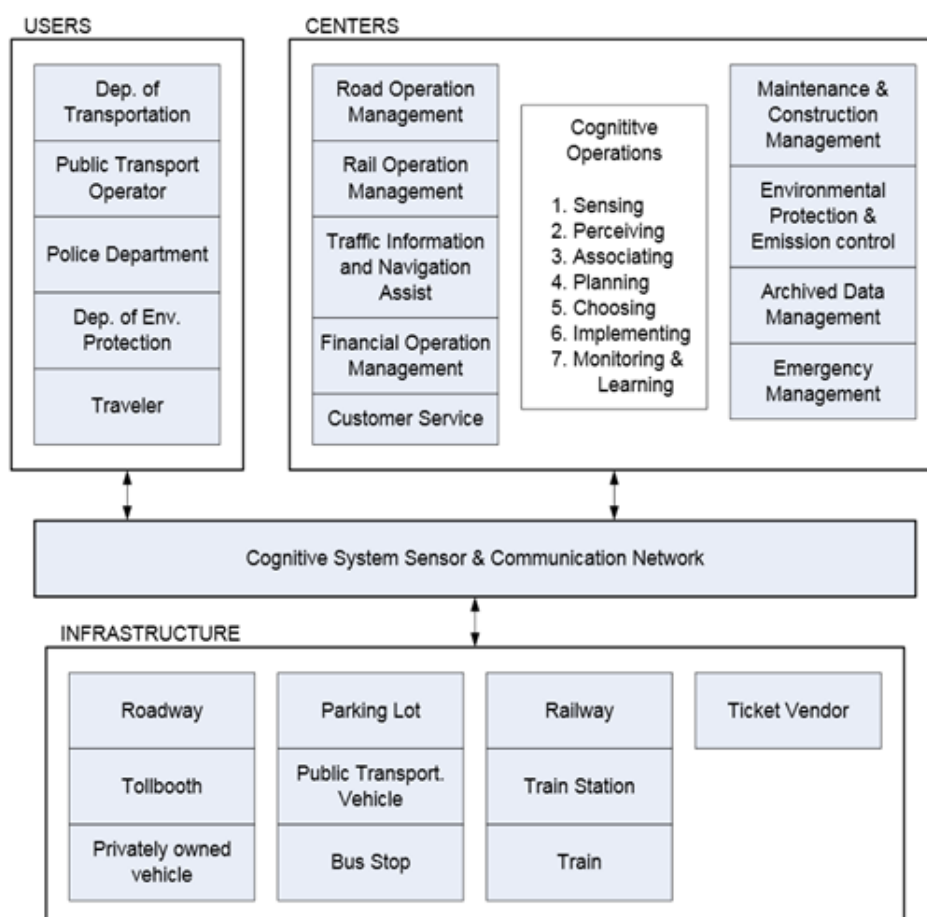
4. Connectivism is a learning theory of the digital age that underlines the importance of social and cultural context in how learning occurs. According to Siemens, learning does not occur entirely under the control of the individual, but within and across networks. Connectivism integrates principles explored by chaos, network, complexity and self-organization theories (Siemens, 2005).

knowledge and innovation through cooperation and competitiveness (Komninos, 2002).

As Moyser and Uffer explain (2016) the information flow in smart cities is usually unidirectional; for example, citizens and governments receive real-time information on urban traffic conditions and they are notified in case there is any emergency or outage. On the contrary, the information flow in cognitive cities is multidirectional; citizens and governments not only receive information but also deliver information to others, such as other devices and sensors, operating platforms or other humans, so that the systems learn and adapt their behavior. Figure 1 illustrates the flow of data, analysis and decision between infrastructure systems, data centers and users for transportation infrastructure.

Cognitive cities approach is not a technocratic approach to urban management and urban governance; it combines the concepts of smart and learning cities and introduces the human factor in our understanding of cities. Cognition and creativity together with the ability to learn become central components that can make it easier for cities to deal with the main challenges of our age: efficiency, sustainability and resilience (Finger and Portmann,

Figure 1.
A cognitive system
for transportation
infrastructure (Mo-
stashari, 2011).



2016). Unlike smart cities approach, urban problems are not treated as solely efficiency problems and cities are regarded complex sociotechnical systems where people, technology and institutions co-evolve. Moreover, ICT is not considered only an optimizing tool, but a tool for collective learning of and by urban systems. Built upon the theory of connectivism, knowledge development is formed through networks and ICT connects different actors among them, people with each other but also with institutions and organizations. According to Finger and Portmann, a city's resilience results from the ability of every single actor in a city to develop autonomously through ICT networks (Finger and Portmann, 2016).

The current debate on cognitive cities is still rather limited, as research on the topic is quite recent. There are already several examples of this "urban labelling" phenomenon where a new urban vision emerges as ideal or utopic and is initially self-reported as an improved version of previous visions. Moyser and Uffer (2016) analyze the challenges of adopting technological solutions within the cognitive city vision, which are political, regulatory, economic, social and technological. In general, despite disapproving the technocratic focus of smart cities, we can argue that the concept of cognitive cities is also grounded in adopting advanced ICT, like big data and artificial intelligence. However, there is a two-fold difference in how technology is viewed through the lens of cognitive cities. On the one hand, cognition becomes the central core of any computer system and their function resembles the human brain. In this context, soft computing has emerged as an attempt to enhance traditional techniques by exploiting the tolerance for imprecision and uncertainty (Zadeh, 1994), basic elements of the human behavior. On the other hand, the role of the individual citizen is fundamental and not inferior to that of ICT, and city's cognition results as a derivative of their constant interaction.

Epilogue

Our understanding of human intelligence has significantly advanced during the last century. Although we are far from clearly understanding the functioning of human brain as a whole, we have managed to apply certain functions of it for the development of computation, as a direct extension of our intellect (Novak, 1997). At the same time, considering the multiplicity of intelligences, we have been able to envision a quite wider spectrum than previous approaches including the intelligence quotient. This theory of multiplicity has also allowed us to consider imagination and creativity as central elements of human intelligence. Utopian thinking as the ultimate expression of imagination, has been historically linked with cities and urban planning. People tend to create visions about the future, fantasizing how cities could evolve based on specific political, economic and cultural circumstances. The main function of utopian thinking lies on the transformative power of intelligence to think beyond the existing, and in this way, to evolve.

Assuming our understanding of human intelligence significantly affects our approach on city intelligence, it is argued that the transition from smart to cognitive cities reflects the evolution of our understanding of human intelligence. Both smart and cognitive cities emerge as ideal models of cities that could tackle current urban challenges, exploiting the potential of the technological achievements of ICT in order for cities to acquire some sort of intelligence. However, the smart city approach adopts a technocratic view of intelligence, similar to our logical-mathematical intelligence, an intelligence that is homogeneous, quantifiable and 'optimizable'. On the contrary, the cognitive city approach adopts a more holistic perspective



on intelligence; introducing the concepts of cognition and learning but also imprecision and uncertainty, intelligence becomes dynamic, heterogeneous and multi-faceted, closer to Gardner's approach on multiple intelligences (Gardner, 2011). Cognitive cities cannot be created from scratch, they emerge through the continuous interaction among people, institutions and technology.

Undoubtedly, technology has a great potential to support tackling the challenges of our rapidly growing cities. However, technological solutions on their own are not going to solve the deep rooted structural problems in cities since they do not address their root causes (Kitchin, 2013). Taking a closer look in the short history of humankind, we witness the double reality of technology; technological developments have contributed, at the same time, to some of the best and some of the worst features in our lives (Sloman, 1978). In other words, technology is able to produce, integrate and destroy cultural phenomena (Bain, 1937); technology extend itself and ourselves far beyond the original problems that gave rise to it (Novak, 1997).

The subversive nature of ICT and their tremendous impact on our lives have been frequently featured in the literature for cities. However, reality is still far from Zenetos' humanistic vision of Electronic Urbanism, where the extensive use of ICT leads to the emancipation of the individual and the dematerialization of cities and architecture (Kalafati and Papalexopoulos, 2006). Yet, technology was a means to this vision, an enabler, a catalyst. So, although it significantly affects how we envision the cities of tomorrow, technology should be considered in its actual dimension; as one structural layer among many other interrelated elements that compose our cities.

Concluding, the contribution of smart cities theory and practice has definitely widened our visible horizon both for possible challenges and risks but also for significant solutions and useful tools in urban context. Cognitive cities appear as an improved approach that is able to overcome the aforementioned weaknesses of smart cities. However, since both theory and practice related to cognitive cities is still quite limited, it remains unknown whether this vision for cities will help us face current urban challenges and, therefore, whether it will help us evolve.

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References

- Afzalan, N., Sanchez, T.W. and Evans-Cowley, J. (2017) 'Creating smarter cities: Considerations for selecting online participatory tools', *Cities*, 67, pp. 21–30.
- Almirall, E. et al. (2016) 'Smart Cities at the Crossroads: New Tensions in city transformation', *California Management Review*, 59(1), pp. 141–152. doi: 10.1177/0008125616683949.

- Alonso, J. M. and Mencar, C. (2017) 'Building Cognitive Cities with Explainable Artificial Intelligent Systems', in 16th International Conference of the Italian Association for Artificial Intelligence. Bari, Italy. Available at: http://ceur-ws.org/Vol-2071/CExAIIA_2017_paper_1.pdf (Accessed: 9 May 2018).
- Angelidou, M. (2014) 'Smart city policies: A spatial approach', *Cities*. Pergamon, 41, pp. S3–S11. doi: 10.1016/j.cities.2014.06.007.
- Bain, R. (1937) 'Technology and State Government', *American Sociological Review*. American Sociological Association, 2(6), p. 860. doi: 10.2307/2084365.
- Chourabi, H. et al. (2012) 'Understanding Smart Cities: An Integrative Framework', in 2012 45th Hawaii International Conference on System Sciences. IEEE, pp. 2289–2297. doi: 10.1109/HICSS.2012.615.
- Effing, R. and Groot, B. P. (2016) 'Social Smart City: Introducing Digital and Social Strategies for Participatory Governance in Smart Cities', in. Springer, Cham, pp. 241–252. doi: 10.1007/978-3-319-44421-5_19.
- Feldman, S. and Reynolds, H. (2014) 'Cognitive computing: A definition and some thoughts', *KMWorld Magazine*. Available at: <http://www.kmworld.com/Articles/News/News-Analysis/Cognitive-computing-A-definition-and-some-thoughts-99956.aspx> (Accessed: 15 June 2018).
- Finger, M. and Portmann, E. (2016) 'What Are Cognitive Cities?', in. Springer, Cham, pp. 1–11. doi: 10.1007/978-3-319-33798-2_1.
- Gardner, H. (2011) *Frames of mind : the theory of multiple intelligences*. 3rd edn. New York, USA: Basic Books.
- Goleman, D. (1995) *Emotional intelligence*. New York: Bantam Books.
- Graham, S. (2002) 'Bridging Urban Digital Divides? Urban Polarisation and Information and Communications Technologies (ICTs)', *Urban Studies*. Sage PublicationsSage UK: London, England, 39(1), pp. 33–56. doi: 10.1080/00420980220099050.
- Greenfield, A. (2013) *Against the smart city*. New York: Do projects.
- Harari, Y. N. (2014) *Sapiens: A Brief History of Humankind*. New York: Harper.
- Hill, D. (2013) *On the smart city; Or, a 'manifesto' for smart citizens instead*, *City of Sound*. Available at: <http://www.cityofsound.com/blog/2013/02/on-the-smart-city-a-call-for-smart-citizens-instead.html> (Accessed: 25 May 2018).
- Hollands, R. G. (2008) 'Will the real smart city please stand up?', *City*. Routledge, 12(3), pp. 303–320. doi: 10.1080/13604810802479126.
- Hollands, R. G. (2015) 'Critical interventions into the corporate smart city', *Cambridge Jour-*



nal of Regions, Economy and Society. Oxford University Press, 8(1), pp. 61–77. doi: 10.1093/cjres/rsu011.

Ingram, R. et al. (1996) 'Building Virtual Cities: Applying Urban Planning Principles to the ...', Proceedings Of The Acm Symposium On Virtual Reality Software And Technology (VRST96, 96, pp. 83--91. Available at: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.5.2688> (Accessed: 19 June 2018).

Kalafati, E. and Papalexopoulos, D. (2006) Takis Ch. Zenetos : Digital Visions and Architecture. Athens: Libro.

Kitchin, R. (2013) 'The real-time city? Big data and smart urbanism'. doi: 10.1007/s10708-013-9516-8.

Komninos, N. (2002) Intelligent cities : innovation, knowledge systems, and digital spaces. Spon Press.

Komninos, N. (2015) The age of intelligent cities : smart environments and innovation-for-all strategies. Routledge.

Komninos, N. and Mora, L. (2018) 'Exploring the Big Picture of Smart City Research', Scienze Regionali, 17(1). doi: 10.14650/88815.

De Lange, M. and De Waal, M. (2013) 'Owning the city: New media and citizen engagement in urban design', First Monday, 18(11). doi: 10.5210/fm.v18i11.4954.

Larsen, K. (1999) Learning cities: the new recipe in regional development - OECD Observer, Centre for Educational Research and Innovation (CERI).

Legg, S. and Hutter, M. (2007) 'A Collection of Definitions of Intelligence'. doi: 10.1207/s15327051hci0301_2.

Longworth, N. (2006) Learning Cities, Learning Regions, Learning Communities: Lifelong Learning ... - Norman Longworth - Google Books. New York: Routledge.

Mattern, S. (2013) 'Methodolatry and the Art of Measure', Places Journal, (2013). doi: 10.22269/131105.

Morozov, E. (2013) To Save Everything, Click Here, Technology, Solutionism, and the Urge to Fix Problems that Don't Exist by Evgeny Morozov. New York: Penguin.

Mostashari, A. (2011) 'Cognitive Cities and Intelligent Urban Governance', Network Industries Quarterly, 13(3). Available at: http://www.academia.edu/801956/Cognitive_Cities_and_Intelligent_Urban_Governance (Accessed: 14 June 2018).

Moyser, R. and Uffer, S. (2016) 'From smart to cognitive: A roadmap for the adoption of technology in cities', in Studies in Systems, Decision and Control. doi: 10.1007/978-3-319-

33798-2_2.

Novak, M. (1997) 'Cognitive Cities: Intelligence, Environment and Space', in *Intelligent Environments: Spatial Aspects of the Information Revolution*. Elsevier, pp. 386–420.

Oliveira, A. and Campolargo, M. (2015) 'From Smart Cities to Human Smart Cities', in *2015 48th Hawaii International Conference on System Sciences*. IEEE, pp. 2336–2344. doi: 10.1109/HICSS.2015.281.

de Rita, D. and Häuber, C. (2015) 'The smart city develops on geology: Comparing Rome and Naples', *GSA Today*, pp. 4–9. doi: 10.1130/GSATG222A.1.

Schuler, D. (2002) 'Digital Cities and Digital Citizens', in. Springer, Berlin, Heidelberg, pp. 71–85. doi: 10.1007/3-540-45636-8_6.

Shepard, M. (2011) *Sentient city : ubiquitous computing, architecture, and the future of urban space*. Architectural League of New York. Available at: <https://mitpress.mit.edu/books/sentient-city> (Accessed: 19 June 2018).

Siemens, G. (2005) 'Connectivism: A Learning Theory for the Digital Age', *International Journal of Instructional Technology & Distance Learning*. Available at: http://www.itdl.org/journal/jan_05/article01.htm (Accessed: 14 June 2018).

Slovan, A. (1978) *The computer revolution in philosophy : philosophy, science, and models of mind*. Harvester Press.

Vanolo, A. (2014) 'Smartmentality: The Smart City as Disciplinary Strategy', *Urban Studies*. SAGE Publications Sage UK: London, England, 51(5), pp. 883–898. doi: 10.1177/0042098013494427.

Zadeh, L.A. (1994) 'Fuzzy logic, neural networks, and soft computing', *Communications of the ACM*. ACM, 37(3), pp. 77–84. doi: 10.1145/175247.175255.



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Geometry

Guest Editor: Dr Ioanna Symeonidou

Assistant Professor, Department of Architecture, University of Thessaly, Greece

The 12th issue of the ArchiDOCT e-journal welcomes papers that explore the role of geometry in architecture, considering the reciprocities between form, structure, material, design-to-fabrication processes, and morphogenetic strategies. Geometry has always been inherent to architectural design and production, however the intersection, crossover and revisiting of traditional as well as computational design methodologies give rise to an unprecedented geometric freedom, new design and production workflows and provide an exceptional opportunity for architectural innovation. Natural forms display a great geometric complexity and engineers have always looked into nature for inspiration and innovation, while currently the advancements in computational design have enabled the interconnections and feedback among disciplines such as physics, biology and mathematics. Inspiration may be found in the geometry of swarm movement, magnetic fields, liquid formations, erosion, plant growth and the underlying logic that produces such forms. Recent architectural history has showcased paradigms where the geometry and form in relation to structural innovation gave rise to exciting architectural gestures such as the hyperbolic paraboloids of Felix Candela and the anticlastic surfaces of Frei Otto. In the years to follow the dynamic modelling of lightweight structures was simulated by contemporary numerical tools for design optimization. The ever-growing design explorations with parametric and algorithmic design tools have opened up the design repertoire to non-deterministic design strategies through computational bottom-up processes and performance-oriented geometric articulations that respond to multiple design criteria. As opposed to former design strategies where decisions regarding the geometry lie in the starting point of the design process, very often the geometry is developed as a result of simulation, the creative process becomes a negotiation of physical or artificial agents that interact and self-organize giving rise to emergent architectural artefacts.

Geometry relates to both representation as well as materialization; there is an intricate relationship between the tool (analogue or digital) and the form. Tools are mediators between the designer and the object of design. This does not only refer to the design phase where pencils, software, code and models are employed to represent the geometry of an object; tools that are used to carve stone, CNC machines or robots have a direct repercussion on the geometry of the produced artefact. As Mario Carpo remarks in the *The Alphabet and the Algorithm*, "all tools feed back onto the actions of their users, and digital tools are no exception [...] manufactured objects can easily reveal their software bloodline to educated observers".

This **ArchiDOCT** issue invites doctoral research essays focusing on any field related to architecture where geometry plays a major role. Proposals may include theoretical/historical approaches and analyses of architectural geometry, as well as contemporary design methodologies that explore the relationships between applied geometry, engineering and graphics, research and experimentation in computational design, virtual reality and augmented representation, analogue vs digital fabrication and optimization strategies. This issue aims to trace contemporary research on geometry across differ-

ent media, and its role within the process of architectural morphogenesis.

Important dates

Submission deadline (full papers): 15 September 2018

Review period: 16 September – 15 October 2018

Revision period: 16 October – 30 November 2018

Follow-up review: 01 December – 15 December 2018

Final revision: 16 December – 31 December 2018

Publication date: 01 February 2019

Submission policy

ArchiDOCT is published twice a year, in July and January. The official language of the journal is English. Submitted manuscripts for review should not exceed 4500 words, including abstracts, references and image captions. The referring system will be the Harvard System. Text should be saved in a Microsoft Word or RTF file, while the supporting visual material (images, diagrams, sketches, tables and so on) should be sent as TIFF files with a resolution of at least 300 dpi. All visual material should be clearly indicated and numbered in the text, along with the respective image captions and credits. Additionally, all manuscripts should be submitted in A4 “camera-ready” .pdf format that gives an idea of how a finalised version looks.

ArchiDOCT only accepts manuscripts from PhD students. In order for an article submission to be considered for publication, the student must be a registered and active member of the ENHSA Observatory (www.enhsa.net/main/observatory), a PhD research portal created to facilitate communication and meaningful information exchange between architecture doctoral students.

Reviewing policy

The peer reviewers are all confirmed educators of architecture coming from different educational backgrounds, with different specialisations and expertise that share the common interest of their doctoral students: to encourage them to publish their work while improving their thinking processes towards academic research writings. Each submitted article is reviewed by two members of the journal's Scientific Committee anonymously.

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