Dancing with the Urban Exaptation

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1 Introduction

The term Exaptation refers to the adaptation random process of the elements that make up an organism, a process that Gould and Vrba define as "bricolage of nature" (Gould and Vrba 1982).

The question arises in the biological field and helps to overcome the evolutionary narratives linearity, prevalent in the twentieth century, in favor of narratives, which, taking advantage of increasingly powerful technologies, introduce unimaginable interpretative potential. Thus develops a scientific process that replaces the "great thinking of nature" with a "thinkering of opportunistic readjustments" of structures already available for new functions, which Gould and Vrba assimilate to a DIY process.

These concepts applied to the study of the city stimulate some questions:

- the city is not an asset "already available" to man, but an artifice created by man, historically subtracting goods from nature. Hence, what is the nature of the city and the structure of its narrative?
- knowing its current structure, what are its main evolutionary processes (unwilling and unable to analyze the entire urban complexity in history in a single article)?
- what is the speed of evolution of these processes?

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1.1 On the Nature of the City

Flash 1. Traditionally the evolution of the city was explained through linear illustrations of its physical-functional evolution (Duby 1980; Dethier and Guiheux 1994), in which the agents are the needs of military defense (e.g., from Palmanova to Haussmann's Paris) and the evolution of the means of production (e.g., from Karl Marx's "Countryside City Dichotomy" to Manuel Castells' "City of Communication") (Castells 1996–1998), passing through the epic of the industrial city which sees Peter Hall as a prominent narrator (Hall 1988). These approaches, which refer to the city as an expression of social and physical capital, two factors that find synthesis in Mumford's monumental work "The city in history" (Mumford 1961), are also significant for the low weight they give to the fundamental generative process: the subtraction of natural resources.
Flash 2. Nature, with its rules and its limits, is the great neglected of urban and economic stories, until Jacob Moleschott broke into the mid-1800s, offering the instruments for a circular view of urban reality based on the metabolism of ecosystems, thanks to the contributions of biology and ecology (Cosmacini 2005).

It certainly cannot be said that Moleschott's vision was at the center of the attention of the city's researchers, who will wake up a century later alarmed by the consequences of this inattention. Only in the middle of the last century, it developed the awareness that the world is a capsule with unsurpassed load limits (Kenneth Boulding's "Earth as a Spaceship," 1966, and Ian McHarg' "Design with Nature," 1969), threatened by human pressure (Paul Ehrlic's "The Population Bomb," 1968, and Paul Ehrich, with Barry Commoner and John Holdren, 1971, proposes the formula I = PxAxT). Nicholas Georgescu-Roentgen will make explicit the principle that the use of resources must not affect bioproductivity, and will support the need for a responsible relationship between economic development and the laws of thermodynamic (Georgescu-Roegen 1998). From here it is born a responsible vision of the economy (and of the development of the city), illustrated in 1973 together with Kenneth Boulding and Hermann Daly in the "Manifesto for a human economy," the foundation of the degrowth theory (Georgescu-Roegen et al. 1973).

The implications of space for these elements are critically anticipated by Jane Jacobs in the fundamental "The death and life of great american cities" (1961), where in the last chapter "The Kind of Problem a City Is" (Jacobs 1961) reflects about the interpretative 'thinkering' of the city leading it back to three stages of:

(1) *simplicity*, dominated by the linear relationship between a few variables;
(2) *disorganized complexity*, dominated by the statistical relationship between an high number of variables, studied through regression analysis, which measures the relationship between variables through the mean and the acceptable correlation error.

Jane Jacobs writes that the city is designed on the basis of average and error, so: "This is what modernist planners thought they were basing their authority on. They knew the numbers and they could accurately, if not exactly, determine how much

sunlight an average man needed. They believed that through the abundant collection of punctual data they could solve all the problems of the system thanks to the averages, and their policies would be out of dispute, simply a matter of scientific facts." The myth of the data was born in this period, as an operational tool to understand and modify the city, and with it an important example of exaptation. The potential of the data is intuited by the US Air Force, which, applying Leontieff's cross-sectoral matrices to the bombing of cities, will inaugurate the practice of "precision bombing," applied to the main interchange and production nodes of European cities after the Second World War. More peacefully, Jan Tinbergen, first Nobel for economics (1969) will apply the same matrix to the Randstad Territorial Plan in the immediate post-war period, giving shape to a metropolitan vision based on interdependencies and externalities, or, rather, to a modern interpretation of the metropolis as a network and a system of networks (Leontief 1986; Tinbergen 1969).

Even the economist Robert Solow will make massive use of data to discover that the wealth of the firm is generated by its externalities (Solow 1956), a concept grasped by Jane Jacobs which understands that equally the wealth of the city is linked to the ability to internalize exogenous knowledge, from which the vitality of the metropolis, dependent on their ability to import important masses of human capital, and, thanks to them, to dynamically develop new knowledge;

(3) *organized complexity*, Jane Jacobs reconnecting to the advancements of studies in biology and computer science contained in the report of the biologist and mathematician Warren Weaver to the Rockefeller Foundation (1958), notes how the mechanical-linear rules of city development, combined with the statistical techniques, are unable to explain their nature, which, she senses, be similar to that of a neuronal network, that is, a system inspired by the functioning of neurons in a biological organism (Weaver 2003).

Thus she overcomes the linear or statistical approach of the city "as a machine for living or producing" (tipical of the modernist thinking), in favor of the city as a "learning machine" (a "machine" that learns from experience), exactly as a neuronal network learns and evolves.

These insights gave rise to the era of the archeology of cybernetics (Lynn 2013) and biology, which will provide the raw material for the global city of bits, and for inequalities and asymmetries.

Flash 3. 1946–1953, in a series of interdisciplinary seminars organized by the philanthropic foundation Macy, which promotes the search for new ideas especially in medicine, the mathematician and statistician Norbert Wiener discusses "cybernetic" ideas, then little known, because they are subject to secrecy sets up US military research, with an innovative interdisciplinary table made up of neuro-anatomists, neurophysiologists, psychologists, statisticians, ecologists, philosophers, cultural anthropologists, sociologists, physicists, and mathematicians (Montagnini 2015).

1958, Richard Feynman at California Technological Institute (CALTECH) holds his famous lesson "There's Plenty of Room at the Bottom," which will be awarded the Nobel Prize in physics, in which he theorizes the exponential availability of matter, thanks to nano-bio technologies, summarized in the famous slogan "how many

British encyclopedias are in a hair" and describes the process of self-reproduction of biological elements (Feynman 1960).

These two elements mark an epochal passage in the study of the structure of the city, in fact, to the binomial Matter—Energy proposed by Roentgen, the communication element is added (thanks to cybernetics), so the elements that make up the city are Matter-Energy-Communication. With the nano-biotechs proposed by Feynman, the replacement of the production processes by subtraction of matter with organic self-production processes begins.

The cycle evolves with the publication in 1991 of "The Computer for the 21st Century" by Mark Weiser which thus begins "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." The path of ubiquity begins with the connection tools directly incorporated into objects, urban infrastructures, buildings and in waiting to be incorporated into the human body (Weiser 1991).

The city intended as machine learning intuited by Jane Jacobs has become reality.

The city born as a functional machine destined to host and order the society functions, is it preparing to become a machine commanded by an elite of men who, through robots, monitor a mass of citizens whose pressure exceeds the biocapacity of nature?

It is a complex discourse that finds an important interpretation in the work led by Mohsen Mostafavi at Harvard "Ecological Urbanism," 2010 and by Shoshana Zuboff "The age of surveillance capitalism," 2019) (Mostafavi 2010; Zuboff 2019).

1.2 On the Main Evolutionary Processes of the City

The paper explains this exaptive world assuming the metaphor of the dance, a clear homage to Donella Meadows "Dancing with the systems" (Meadows 2009).

So the narrative takes as a driving force the Vitruvian man in his radical mutations and as plot the chaotic and casual "dance" of disruptive events (interpretable also in terms of exaptation) accompanying the manipulation of space evolution.

The structure of the story, therefore, is based on two great "dances:" of man searching to increase his skills in a race that sees him to compete (or to succumb?) with robots, of man in search of coexistence with nature for a development model compatible with the biocapacity of the earth.

The "dances" are developed thank disruptive events: (1) the evolution of man–machine relationships in a dematerialization process leaded by the route from Architecture Machine to Citizen-Environment Interactions, (2) the evolution of man–nature relationship, in the passage from Holocene to the Anthropocene, (3) the nano-biotechnologies world up to the bionic city.

These events bring out new multiple design alphabets (environmental, architectural, economic/social, technological, …) substantially differents, because connected to the different rules of manipulation of nature, human resources, physical space, and bits.

From the ability that man will have to create new approaches to knowledge at accelerated rates, to develop synergies between new alphabets, the success of urban communities, in harmony with man and nature, will depend.

1.3 On the Evolution Speed of Urban Processes

To interpret an exaptative process it is essential to know the nature of the materials that make up the phenomenon. In the case of the city, knowledge has advanced exponentially since the second post-war period, with Wiener and cybernetics, Feyman with nano and biotechnology and Roentgen with the bioeconomy, to make a further leap in the early years '90 with Wieser and ubiquity.

With the expansion of cognitive processes, the narration of the elements that make up the city has changed: in just over half a century, the historical narrative of the city made up of matter has changed, to the city made up of matter—energy-communication. This narrative has opened up new operational scenarios, indispensable for the survival of the earth (and with it of the mankind):

- the transition from the mechanical mode of production by subtraction of matter to the biological one of the recombination of matter;
- the transition from a "discreet" system of relationships to a "continuous" system, with the consequent revolution of the rules of social relationship and space that govern our communities.

The first point is the prerequisite for an economic revolution that has been announced, but has never been seriously addressed so far, the second for a social revolution based on "open" governance systems, thanks to continuous feedback between communities and civic representatives. But, as Henry Kissinger points out in his famous article "How the Enlightenment Ends," in "The Atlantic," man is unprepared to face such a cultural leap (and perhaps he does not have the capacity) (Kissinger 2018). So the narration of the city, starting from the second post-war period, is a synthesis of information and cultural asymmetries to which contribute: the plurimillennial culture of the nature and church, the secular culture of the merchant, the decennial culture of the man life, who barely integrates with the real time of its decisions.

In essence, it was claimed to interpret and act on the city with the knowledge and rules of the first industrial revolution, so in the last 50 years human actions, with dramatic acceleration, have annihilated the ability of many ecosystems and species to maintain themselves, as they did in the most stable conditions, that prevailed for at least 11,000 years.

The reference to exaptation is therefore useful because it reminds the world of city researchers to the complexity and times of the biological world at the origin of the urbanity, and, consequently, to the urgent need to renew our knowledge, inadequate for maintenance of such complex systems.

1.4 About the Urban Dance

The narrative of the urban structure complexity, as highlighted in the introduction, imposes the transition "from the great narration of nature (in our case of the city)" to a "thinkering" of opportunistic readjustments of heterogeneous components (environmental, social, economic, technological …) in line with the DIY model proposed by Gould and Vrba.

So, this article takes shape on the DIY model. Taking the idea of Jane Jacobs as a reference, the city is not a machine for living or working, but a machine for learning, the city cannot be explained as an intentional sequence of events but as a series of surprise, or sudden, radical shift in preferences or goals, as well as vicious cicles that may stifle its evolution (Ciborra 1991). So the evolution of the urban environment is based on a continuous adaptation and learning processes reshaping continuously the physical, natural, and social context.

Equally, for Donella Meadows "We can never fully understand our world, not in the way our reductionistic science has led us to expect. Our science itself, from quantum theory to the mathematics of chaos, leads us into irreducible uncertainty. We can't keep track of everything. We can't find a proper, sustainable relationship to nature, each other, or the institutions we create, if we try to do it from the role of omniscient conqueror."

Thinkering successfully in a world of systems requires more of us than our ability to calculate. It requires our full humanity—our rationality, our ability to sort out truth from falsehood, our intuition, our compassion, our vision, and our morality. Concepts that Donella Meadows synthesize with the metaphor of the dance, whose main elements are

- Get the beat.
- Listen to the wisdom of the system.
- Expose your mental models to the open air.
- Stay humble. Stay a learner.
- Make feedback policies for feedback systems.
- Pay attention to what is important, not just what is quantifiable.
- Expand time horizons.
- Expand thought horizons.
- Expand the boundary of caring.
- Celebrate complexity.

So, the thinkering of urban evolution is here explained with the "dances" from "Vitrouvius man" to "City Brain."

The article focuses on the topical moments of the evolution of the man-city relationship under the pressure of technological progress, especially in communications. It therefore marks the passage of man from the labor force of the industrial city to the human resource necessary for development of the city as "machine learning," up to its transformation into a robot, due to the continuous incorporation of machines, in a problematic relationship with the "smart city."

2 Urban Dance: Man, Machine, and Urban

In time the role of man changes radically, passing from the Vitruvius man enrolled in a physical environment, to his "liberation" from the walls with Le Corbusier Modulor, to his immersion in the waste of the second industrial revolution, to the supremacy of his neuronal dimension with respect to the physical one, his connection with the bits, his substitution with the robots.

These tsunami of changes, starting with the harmony between man and artifact, are today arrived to a contradictory step: with the substitution of man with robots and with the genetic manipulation of the human body. These great exaptive processes are here explained thank the technological passage from esomachines to endomachines at the origin of radical changes in the relationship man-machine-environment. In fact, we quickly passed:

- from the realization of cumbersome mechanical exomachines symbolized by the relationship Man-Cadillac (Banham 1960), outcome from mechanical technological processes, working by subtraction of matter;
- to the realization of nano biological machines, working inside the human body, thank biological self-production process thinked in 1959 by Robert Feynman. An idea developed in form of molecular machine by Sauvage, Stoddart, and Feringa (Nobel Laureates for Chemistry 2016).

In half a century we passed from the production by subtraction of matter of the industrial revolution to the generative production of the biological revolution, passing through the revolution of connectivity, between people, between things and between people and things. This is the fourth industrial revolution, or, if you want, an important step in the process of exaptive change of man and the city, which I will try to interpret, at least for the relationship among connectivity-man-environment (Fig. 1).

2.1 From Architecture to City Brain

In March 1946, organized by the philanthropic foundation Macy, which promotes the search for new ideas especially in medicine, Norman Wiener (philosopher and mathematician), together with a group of scientists composed of neuro-anatomists, neurophysiologists, psychologists, statisticians, ecologists, philosophers, anthropologists, and sociologists discuss ideas that will underpin "cybernetics," a scientific field hitherto under the hood of secrecy, imposed on military research by the US Department of Defense. A path begins to substantially evolve the knowledge of the city, which will give rise to unthinkable operational and design potential. Synthetically, that discussion will open two fields:

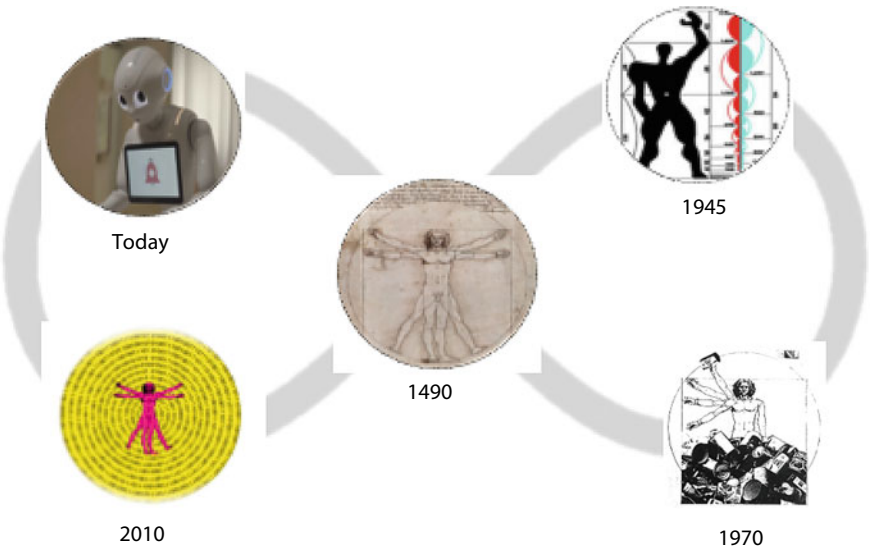

Fig. 1 From Vitruvius man to robot

- the parallelism of the computer with the human brain, which will begin, about twenty years later, starting from the experiences of Architectural Machine, to the great adventure of the augmented capabilities, which will follow:
- the concept of "ubiquity" applied to the city (late 1990s), thanks to the integration of man's increased capabilities with the network (thanks to the Internet), and subsequently to the synergy between the computer-human brain and objects;
- the current morphology of the "City Brain," capable of manipulating data and returning them in terms of services (Feng et al. 2019);
- a substantial advance in the management of governance processes, thanks to the increased cross-fertilization between technology and neurophysiology on the one hand, and, on the other, to the emergence of circular causality notion in livings and in society, with the consequent vision of the government of the city as an ecosystem, articulated in a system of interconnected circular random processes, as happens in the biosphere.

And precisely circularity and cross-fertilization require "open" governance systems (radical evolution of historical "hierarchical" governance systems) between all stakeholders, which operate on the basis of feedback (a concept developed by Jay Forrester in his proposal for Dynamic Systems which will be widely disseminated with the research "The limits to growth") (Forrester 1989).

We are therefore in the presence of a radical evolution of the first industrial revolution, the revolution of the "dark satanic factories," which represented the devaluation of human arms in the face of competition from the machine. With the advent of cybernetics, the modern industrial revolution begins, which is linked to devaluation of the human brain, at least in its simplest and most repetitive decisions.

Wiener says: "Of course, just as skilled workers somehow survived the industrial revolution, so the skilled scientist and administrator can survive the latter. However, once the second revolution has taken place, the average human being, of mediocre ability, will no longer have anything to sell that is worth buying." The competition between man and robot has begun in a city where the goods are produced at marginal cost 0 and where it's great the surveillance of people.

Furthermore, Wiener understands very early that it has to do with a technology not of "matter/energy" like in the past, but the one "of information," subject to new laws. The former had always been interested mainly in the production of a large amount of energy (e.g., steam machines, hydraulic turbines connected to dynamo etc.), its transmission (e.g., with rotating shafts or high voltage lines), its transformation into other forms of energy (such as transformers, transducers), to its use (e.g., thermal or electric motors, heating systems, etc.). On the contrary, generalized information technology is interested in:

- the production of information (by the brain of a person speaking or by a device that automatically sends a stop signal to another, such as the thermostat which switches off the refrigerator motor when the desired temperature has been reached);
- its transmission (on telephone lines, telegraphs, etc.);
- its transformation (noise filtering, coding, etc.);
- its use by a human being or a machine.

The vision of a new discipline, very influential on the development and form of urban environment, that focuses entirely on information emerges, requiring very low energy levels. It is the science to which Wiener in 1947 gives the name of "cybernetics."

Here the story (or dance) of the city becomes complex due to the cultural and cognitive asymmetries of the parties involved in the development of the city (and the strength of the conservative cultures that dominated the study and design of the city), only in 1968 the adventure of Architectural Machine starts, in 1990 the concept of ubiquity and nowadays the new vision of "City Brain" consolidate.

2.2 The Architectural Machine Adventure

The "Computer Graphics in Architecture and Design" conference at the Yale School of Art and Architecture (1968) marks the start of an important step of modern design. It is marked by the transition from Le Corbusier's "machine à habiter," based on the supremacy of the relationship between building–bulky and passive installations, developed between the first and second industrial revolution, to an architecture based on the relationship between building and computers, the miniaturized and interactive systems of IT revolution. The purpose of this new generation of architects and technologists is to initiate egalitarian design processes, aimed at overcoming the role of the designer superimposing on people, that is, overcoming the architect's "genious

role" and the formal standardization of the International style, in favor of informed planning processes, led by citizens.

Gordon Pask argues in "The architectural relevance of cybernetics": "we overturn the design paradigm, focusing on the interaction between the environment and the people who inhabit it, instead of the usual interaction between the designer and the physical system he designs" (Pask 1969).

With this trend also begins a new dimension of architecture aimed at dematerialisation, marked by the relationship between atoms and bits, to say it with Nicholas Negroponte. Thus began the decline of the "Victorian" vision of architecture, based exclusively on the removal of matter, in favor of a design dialogue that exploits the opportunities of new technologies, such as nano and biotechnology, which were born in those years. The result is the start, at the beginning of the 70s, of a modern architecture, sustainable, aiming to increase human resources, thanks to the "increased intelligence, from the availability of new machines and the decrease in the load level of urban interventions, thanks to dematerialisation.

The new design process is in continuity with the thought of the metabolic movement:

- with regard to the role of the architect, who, says Kisho Kurokawa "… should not propose ideal models for society, but should conceive spatial infrastructures that the citizens themselves must make operational;"
- with regard to the synergy between physical achievements and the metabolism of natural resources, confirming the overcoming of the linear design model, typical of Western thought, in favor of the symbiosis, typical of Eastern thought, among all the elements, biotic and abiotic, which contribute to the realization of a project.

A symbiosis confirmed by Christoper Alexander, according to which the city is given by the interdependence between the fixed parts that make up the urban morphology and the variable parts made up of human resources, biodiversity (especially the animal one), the goods that circulate there, the effects of the infrastructures operation. Its development is not given by proceeding in large blocks, therefore on the idea of replacement, but on gradual growth, therefore on the idea of rehabilitation (Alexander 1966).

Shortly, The Vitruvius Man, thanks to modern computers, gets rid of the architect's demiurgical presence. This was the thought of the anarchist architects Nicholas Negroponte, Cristopher Alexander, Bob Mitchell, Alain Kay, and, in Italy, Giancarlo De Carlo. Their motto was "we are all architects" thanks to the "architectural machine" computer.

The computer use generates a new alphabet based on the deconstruction of the architectural language (Alexander, Pattern language), on its logic reconstruction and on new machine operative rules (Negroponte, Toward an Architectural Machine). The modern software (today in use) for design and geographic mapping is born.

Cedric Price is one of the great empirical interpreters of the new opportunities offered by cybernetics and information technology to architecture and the development of the city, thanks to his proposal of architecture based on improvisation. Starting from user requests, coded in constantly evolving software programs thanks

to learning, anticipation, adaptability, architecture is able to adapt in real time. Price's design proposals stem from his sensitivity to the profound social and territorial transformations that began in the second half of the 1960s, which were taking shape in profound processes of deindustrialization and unemployment. The outcome is the proposal of design solutions based on provisionality, improvisation, and interactivity, highly adaptable to the volatility of economic and social conditions, with respect to time and space (Obrist 2003).

In the time of uncertainty and instability Price's work represents a new approach to design, based on a holistic process of construction, reassembly, dismantling.

To cope with the profound social and economic crisis, the buildings and the territorial planning that he proposed were aimed at increasing knowledge: his reference model was the spontaneous organization of "street theater," which was the starting point for the proposal of:

- buildings inspired by the model of the bridge crane, capable of changing in relation to changes in objectives and programs (the best known being "Fun palace"). The input of the building transformability were the citizens' preferences on how to use and occupy the spaces, who, thanks to software and computers provided the operating indications and feedback for the realtime transformation of the buildings;
- complex territorial structures, as Potteries Thinkbelt, capable of developing new systems of social, economic, and productive organization. The structures were divided into: static elements (the railway network and the logistic bases) intended to manage, thanks to an interactive network powered and controlled by computers and emerging information technologies, a system of mobile teaching units, which exploited the opportunities of the railway wagons for the transport of containers. These mobile didactic units were conceived as a quantum information system, the logistic bases were inspired by a large system of computer circuits. Potteries Thinkbelt defines a new kind of architectural monumentality, not a large static building, but an articulated field of discrete objects and diffuse events, similar to the structure of an electronic circuit;
- advanced organizational models: Price's project proposals are based on a wide agenda of opportunities, fueled by users' preferences, and on the ability of the project manager to develop an agenda capable of illustrating new projects' opportunities to unsuspecting citizens. With the "Generator" project, the modern management system for complex interventions was born, based on two roles, the "polarizers" and the "facilitators," able to catalyze on-site the interpersonal dynamics and logistical needs of users. The "polarizers" should have encouraged users to take advantage of the new opportunities of the project and stimulate their interactions, the "facilitators" should have given instructions to make the users' wishes operational, training them to use the individual systems and to sensitize them to the opportunities of the place.

Price sensed that the new ways of urban, economic, and social development required a temporary and agile architecture, capable of adapting not only to inevitable changes, but also to favor and anticipate social transformations (Fig. 2).

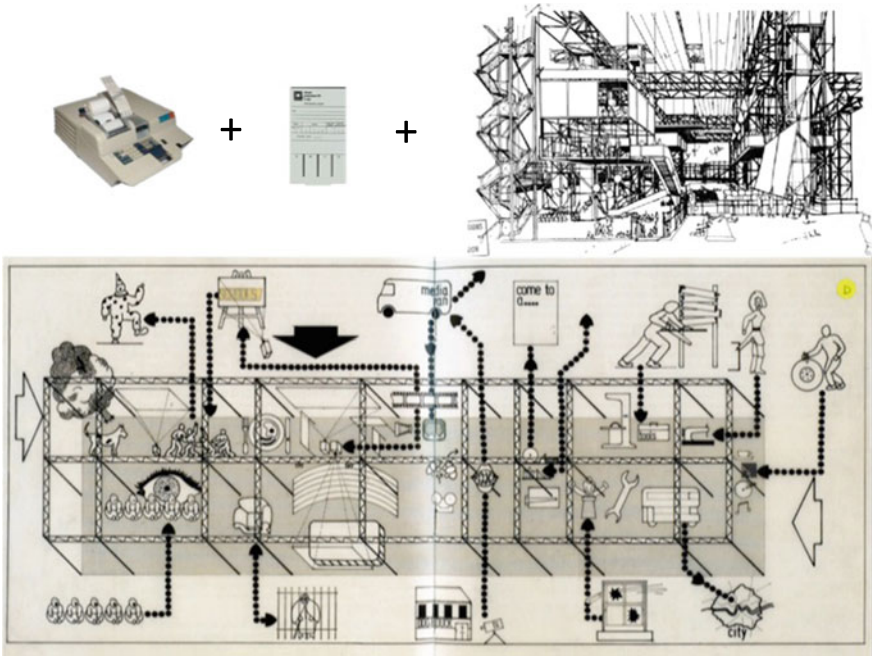

Fig. 2 Cedric Price idea of interactive building: Fun Palace, 1961

Nicholas Negroponte, founder of Architecture Machine Group first (1968) and then of MIT Media Lab (1985), develops his thinking on architecture inspired by classic models to radically renew them. His idea of "Architecture machine" is ideally linked to Le Corbusier's "Machine à habiter"—in terms of legitimizing the machine as a fundamental component of the architecture project; while from an organizational point of view its reference model is the Bauhaus, due to the presence of different disciplinary skills, whose intelligence is increased by the availability of new machines (Negroponte 1970, 1975, 1995).

Negroponte sees technology, like Alexander and Price, as a tool to develop a hypothesis of "spontaneous" architecture, in which it is not the architect with the sum of his historical and cultural experiences that impose the project on the user, but it is the latter, supported by the tools of artificial intelligence, that leads the project, thanks to the new machines that rise to the collective mind capable of recognizing the morphology, the rules of space management and solving the aesthetic data on the basis of a functionality which is cultural, custom, and urban.

Thus develops a working and design method that makes a particular use of the machine, so that it does not place itself on the plane of mimicking-emulation of man's thought, but provides his "assistance" and his skills in the IT field.

> We are simply interested in introducing and promoting machine intelligence that stimulates design for a better life and allows a whole series of self-evolutionary methods", Negroponte (1970).

ArcMac, in the idea of Negroponte, was supposed to transform the design process into a dialogue intended to alter the traditional man-machine dynamics. He wrote: "The dialogue of mutual understanding would have been so intimate, even exclusive, that it would have been impossible to realize for only one of the parties. Without doubt, in such a symbiosis, it would not have been only the human designer to decide when the contribution of the machine was relevant" In order to incorporate the project objectives and to assimilate the aims of the users, the machine should have been equipped with artificial intelligence," because all the design procedures, together with rules or truths are tenuous, if not even subversive, if used out of context or regardless of context." Intelligence for Negroponte is therefore not a passive quality, but an active one, expressed by behaviors and increased over time.

Negroponte also senses that the computerized processes would not be limited to helping us in the design, but, in their evolution from tools to environments, they would have merged into the physical part of the buildings.

This would open up a series of design strategies:

1. the new building materials will be aimed at creating updated forms of the past;
2. the new materials will simulate the processes present in nature, thanks to their ability to assemble and disassemble continuously;
3. the buildings will be associated with robotization processes, so they will qualify not only for their physical characteristics—technological level, industrialization processes, automation levels—but also for some subjective properties, such as autonomy and desire level. Consequently, their representation will be both material, linked to their physicality, and abstract, linked to their ability to develop random processes.

With this last observation the horizon opens to the "ubiquitous city" thanks to the fusion of material and immaterial, that is the connection of atoms and bits, which Negroponte will develop in the "City of news" research program (1975) and in the book "Being digital: atoms and bits "(1995).

These latter contributions define the structure of objects, architecture and the city as a compound of matter—atoms—and connectivity, thanks to intangible resources—bits.

Just as in the previous era of machines, designers planned following the rules of mechanics, according to the metaphor of the work chain, in current time, the global computer networks, the"time-shared" activities, the associative activities on the internet, define an environment comparable to a membrane of virtual spaces and activities. Consequently, Negroponte maintains that the organic development model of the city should be able to represent not only its physical development but also the life generated by the web, thus managing to connect operationally the relationship between atoms and bits and between representation/physical design of the city and representation of the cognitive systems expressed by its citizens.

With the fusion of computerized processes in objects (on a par with buildings and infrastructures), thanks to the rapid expansion of miniaturization, an important, probably fundamental, passage begins in the narration of the evolution of the city, in

that to the history of the relationship between architecture and TLC (therefore matter-connectivity), which has been summarized so far, modern history of the energy-economy relationship will have to be added. Started in the decade from the mid-60s to the mid-70s, it has among its main exponents Kenneth Boulding, Nicolas Georgescu-Roentgen, and Hermann Daly, who will give life to the school of ecoeconomy and of degrowth movement. With these, of course, the physicist Robert Feynman (Nobel Laureate 1965), who in 1958, with his essay "There's Plenty of Room at the Bottom," opens to the knowledge of nanotechnologies and biologic production processes.

Thus, in the 1970s the founding elements of the interpretation of the modern city, which we have owed to cyberneticians since the late 1940s, became operational. At the same time Feynman "reopened the dances," marking the way for a city with exponential development opportunities, in contrast to the dominant theories of the limit of the biocapacity of the earth. This complexity of "dances" confirms that the narrative cannot be linear, because it is dominated by asymmetries. The exaptation will have to equip itself for another dance, that of the narrative of the relationship between city and resources.

2.3 The City of Ubiquity

In an innovation process whose main stages are ARPANET (1969), the WEB (1990), and the CLOUD (2010), communications infrastructures constantly change nature. From a machine to produce projects it becomes first machine to produce sociality and then machine to produce services, with the XaaS (All as a service) process: the fourth industrial revolution is started (Fig. 3).

With the enormous expansion of the potential of the computer + Internet, the fundamental question of the integration, in the construction of the city, of matter (and of the "machine") with the immaterial opens up.

The first era of the computer (from the 60s until the end of the 90s) was marked by machines designed to expand human capabilities, a phenomenon that introduced the transition from inspired organizational (physical and social) design models optimization of the production chain (see Giedion, "Mechanization take Command") and

Fig. 3 From Internet to Ubiquity

models inspired by operational research, intended for the optimization of relationship systems, thanks to the possibility of feedback (see Forrester, "Systems Dynamics").

This scenario is destined to evolve radically with Mark Weiser's article "The Computer of the 21st Century," published in Scientific American in 1991, which introduces the concept of ubiquity into production and organization.

Indeed, Wieser says: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Wieser proposes the vision of a process that from the "standard PC" was diversifying and proliferating through interconnected computer networks, introducing a series of fundamental concepts: the dematerialization of relational and production processes, organization by networks and relational platforms.

Concepts that undermine traditional morphologies, both social and physical, based on the concept of the boundary and the "finished" geometry of places, in favor of acentric processes.

With Wieser's article, the central problem of design will become the symmetry between "closed" and acentric forms.

The evolution of Wieser thinking opens the field to three new phenomena: virtual reality, artificial intelligence, "user agents," but Weiser opposes a strong criticism of this kind of evolution.

2.4 From Ubiquity to Citizen-Environment Interactions

In the third phase, the interactive communication system, after supporting design and sociality, becomes a complex technological system, thanks to the connectivity between objects, produced by Cloud + IoT (Internet of Things): the Smart City is born and evolves rapidly through these stages:

- *Smart City* 1.0: guided by technological companies with the objective of controlling territory and citizens (the myth of fear and security);
- *Smart City* 2.0: guided by the municipality to improve services to citizens;
- *Smart City* 3.0: guided by co-creation with citizens and experimenting forms of proactive democracy (Fig. 4).

In the Smart City, instead of dealing with individual, personal desktop computers, laptops, tablets, smartphones, etc., the experiences and interactions of humans with "computers," will increasingly take place in the context of interacting with "smart artifacts" integrated into the environment, constituting "smart ecosystems." This has serious implications for the research area currently called "human-computer-interaction." It includes also a shift in terms of scale and context, ranging from individual devices for personal activities to multiple devices used in group activities and social interactions. This is followed by the progression from smart rooms to smart or cooperative buildings and their extension to smart urban environments as, e.g., smart cities and airports. The trend toward more comprehensive application contexts requires a corresponding shift from a mostly individual person-based, user-centered

Fig. 4 Smart ubiquitous city pose the classic Cedric Price question: "Technology is the answer….but what was the question?"

design approach to a multiple people and multiple devices-based, citizen-centered design approach for smart environments, we are confronted with, in the urban age. The ubiquitous and pervasive deployment of smart technology in urban environments has serious implications for privacy and security issues.

This goes along with an increasing trend of using artificial intelligence for algorithm-based automation and autonomous systems resulting in a loss of having humans in the loop and in control. Thus, the future of human-computer interaction is characterized by the challenge of addressing the corresponding design trade-offs and the need to rethink and redefine the "smart everything" paradigm in order to move beyond "smart-only" cities to Humane, Sociable and Cooperative Hybrid Cities and Societies (Streitz 2018).

The goal is to build Humane, Sociable and Cooperative Hybrid Cities reconciling people and technology. This implies to foster and enable the following actions and requirements in the town construction (Norbert Streitz, The Future of Human-Computer Interactions):

- establishing a calm technology providing ambient intelligence that supports and respects individual and social life;
- respecting the rights of citizens, especially in terms of privacy and security;
- viewing the city and its citizens as mutual cooperation partners, where a city is "smart" in the sense of being "self-aware" and "cooperative" toward its citizens by supporting them in their activities. This requires mutual trust and respect for the motives and interests of all stakeholders involved;
- acknowledging the capabilities of citizens to participate in the design of the urban environment, especially with respect to their local expertise, and stimulating their active participation;
- motivating citizens to get involved, to understand themselves as part of the urban community, to be actively engaged by contributing to the public good and welfare;

- enabling citizens to exploit their individual, creative, social, and economic potential and to live a self-determined life, and thus
- meeting some of the challenges of the urban age by enabling people to experience and enjoy a satisfying life and work.

These are some of the demanding actions and requirements that urban design has to face with for the next 20 years. Although addressing different levels of scale, many of these requirements can be generalized from Cooperative Cities to Cooperative Societies.

2.5 The City Brain

The narration of the city in its transition from physical structure to ubiquitous structure cannot be separated from the description of the system that allows its operation: the City Brain, whose key elements are

- the central nervous system: it is made up of the Cloud, which through the Cloud Computing procedures is able, as well as to collect data, to: (1) manipulate them, thanks to Big Data, AI, Machine Learning, Deep Learning, (2) organize them, thanks to the Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS), (3) socialize them, thanks to SNS (Social Network Systems);
- the nervous motor system: made up of the Internet with its stages of evolution (IoT, Mobile and the related technological passages G4, G5, …);
- the peripheral nervous system: constituted by Edge Computing with its property, thanks to the "reflex arcs" which don't depend on the central urban brain.

The City Brain infrastructures allow the "neuronal" interactions between the different physical and social elements that make up the city and its environment, from this point of view, the Smart city poses severe problems of social organization, as it obliges to rethink:

1. the neuronal organization of the community: Smart community, Smart Citizenship, Smart Government …;
2. the neuronal organization of the city's functions: Industry 4.0, Smart building, Smart traffic, Smart Health, …;
3. the governance of relationship between human resources and robots, with regard to employment and ethical problems;
4. the governance of human activities—environment interactions (Fig. 5).

This rethinking cannot ignore in the city design the role of the Public Administration Social Net infrastructure is substantially different from that of the private social networks, organized by the communication majors (Google, Facebook, Instagram, …).

These Majors collect data, that are a private and collective good of citizens, essentially by not paying them, generating surplus value through their "manufacturing"

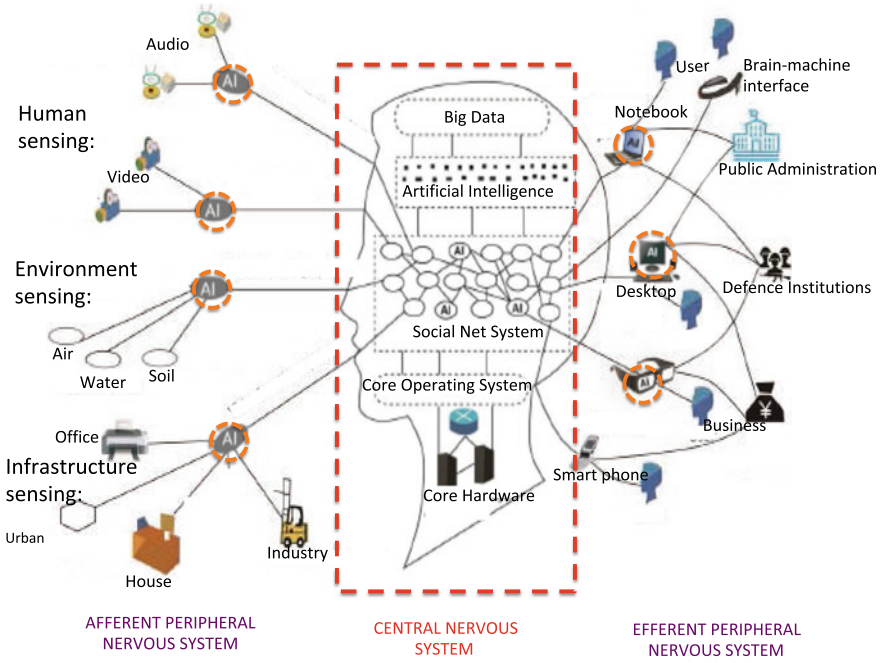

Fig. 5 The urban information system clone of the human nervous system: to increase human capacity or to replace them with robot?

(A.I phase and related operations) and their marketing (through Social Net). The municipality that has a primary asset, both individual and common (the data of citizens, public organizations, nature, historical heritage …), instead is called to initiate social enhancement processes, through the same activities of "manufacturing" and distributing data.

Therefore, through the organization of the social net, the public administration should re-appropriate the role of producer with the aim of generating social added value (Maistrello 2006).

To achieve this step, a process of up-to-date culture of Public Administration must be started, as it must be able to manage the difficult transition from governing discrete systems in a linear way, to governing complex systems of "open" flows.

In fact, social networks operate according to the emergency rule: that is, starting from simple rules (or elements) they are able to self-generate complex schemes (or structures), which the mere sum of the parts would not have left to imagine. So if the complex system is managed with the rules of the linear, unforeseen situations are generated, which the administrators are not able to govern.

This matter proceeds at accelerated way because the number of social interactions "out of control" increases exponentially in relation to the number of components (according to Moore's law), generating a system of unpredictable/uncontrolled social behavior.

The design of the Municipal Social Net (s) consequently consists in the design of open and networked cooperation systems, producing value from every element of the urban environment (citizens, natural capital and physical capital) thanks to the detection of any type of behavior and expectation.

This is possible by overcoming the social network, intended exclusively for man-man interaction, thanks to the new "ubiquitous" infrastructures, that is, made up of material elements (buildings, offices, shopping centers, roads, urban systems, …) which incorporate intangible services through the Cloud-Big Data-IoT processes.

So every building, every car, every shopping center, every plant, every citizen will have a connection code to the social network, managing automatically information in real time and also interacting with other people or things, involving human-human, human-things, and things-things interactions.

This implies overcoming the idea of the social net as an increasingly costly and conflicting structure of power centralization, in favor of a "neuronal" infrastructure, "listening" to the city, producing new social value.

This is an operation of the society redefinition comparable to the advent of writing.

2.6 Dilation of the Idea of Space and Dilation of the Idea of Wealth

The process of continuous expansion of the idea of space, thanks to the integration of connectivity tools in physical structures, generates an important change in the process of accumulation and distribution of wealth among citizens.

Thus began a "dance" fueled by the revision of the neoclassical theories on economic development asserted first by Robert Solow and after by Robert Lucas, in synergy with Jane Jacobs, ending with Paul Romer (from 1956 to 1990). This path is of fundamental importance for the explanation of the city evolution, as it is marked by the passage from the supremacy of physical capital (expressed in artifacts, plants and infrastructures and financial resources) to that of a holistic system in which interact four driving forces: ideas, institutions, population, human capital (expressed by education, research, and development).

The main growth factor of these driving forces regarding the economy, according to Solow, is the exogenous factor of technological progress. An intuition that is completed by Lucas and Jacobs, who underline the role of the city (and, in particular, of its size and dynamism) in development, because human capital, generator of technological progress, is concentrated in it.

A concept sustained also by Romer (1986), who maintains that development is in relation to an unlimitedly available good, consisting of ideas, which are introducing a series of changes in our way of thinking about development, as follows:

- they are non-rival goods, as they can be used simultaneously by a large number of people without generating congestion or exhaustion;

- develop new technologies, such as biotechnology, which help demolish the fair of diminishing returns, which has obsessed the economic thinking from Ricardo to Keynes. On the contrary, new technologies create increasing returns, because new knowledge, thanks to research, starts new products. Furthermore, in the design and construction, the new technological frontiers, based on dematerialisation and biotechnology, allow to create products by drastically lowering the withdrawal of resources from nature, thus minimizing the impact on the load capacity of the earth—they generate the fall in production costs, the centrality of investments thus shifts from production to research;
- the production of ideas is inseparable from the effects of scale, and therefore confirms the fundamental role of urban concentration and with it the positive reading of the phenomenon of megacities and globalization;
- they are based on organizational models (also of the city) not competitive but linked to the symmetry of relationships, thus collaborative;
- the latter two factors (effects of scale and organization) are often considered together, but are logically distinct; the organizational effects have attracted more attention but the scale effects are more important to understand the great change in human history that we are living.

This path inspires an urban design model in which the driving force is human capital, so the primary development infrastructures of the city are those that feed knowledge (formal and informal), research, and development activities, to which must be added the infrastructures to protect human capital, such as healthcare. Hence, according to Paul Romer, the purpose of urban planning is to "identify additional units of public good, in order to prevent the decrease in the productivity of human capital". On the contrary, if the city is conceived as a simple agglomeration of productive factors (in our case manufactured goods or physical spaces anyway), as happens in current urban planning practices, the centrifugal forces linked to rent will prevail.

Furthermore, a design based mainly on the increase in physical capital (e.g., through the construction business), according to Solow, does not produce long-term effects, because what can affect growth is, ultimately, only the rate of introduction of new technologies, which affect 80 % of the development processes. The purpose of urban planning is therefore not to exclusively satisfy the needs of resident citizens (to satisfy endogenous needs), but to capture the innovative flows of knowledge (the exogenous flows of human resources), internalize them in the development processes of the city, to generate export flows of goods and knowledge and to favor the integration in the city network.

The wealth of the city is thus determined by the quality of its infrastructures and places, that favor the accumulation of knowledge, the development of skills and empathy.

3 Conclusions

As mentioned in the introduction, the adaptation of the concept of exaptation, born in the biological field, to a multidisciplinary field such as the city is not easy. It is true, as Andriani argues, that the effort to adapt this concept to areas different than that of the living is consolidated, however these efforts mainly concern a sectoral "expansion" (exaptation and technology, economics, physics, social sciences, …), in the case of the city we are faced with a system with an infinite number of variables, the aggregate trend of which cannot be determined a priori, hence it could be said that the nature of the city itself is exaptative (Andriani and Carignani 2014; Andriani and Cattani 2016; Andriani et al. 2017).

The article illustrates the complexity of the urban structure by referring to Jane Jakobs' question "The Kind of Problem a City Is."

From the narrative it appears that the dynamics of the components of this vision take on an exponential acceleration in relation to the development of the "augmented capabilities" of man, but also an exponential confusion for the inability of man to manage this structure, changing in a way unpredictable due to the different forms of exaptation activated by the context elements that are proposed according to the Donella Meadows metaphor of the dance, to mark the improvisation and creativity of the variations, from which the emergence of unpredictable (perhaps one might say disruptive) phenomena. The vision of the structure of the city and its non-linear variability is traced back to a series of questions:

1. whom is the city made? Over time, the construction of the city has gone from the supremacy of the land factor to that of human resources, as its vitality depends on the quality and quantity of knowledge and innovation processes. So to the rational space of the city, with its figures inscribed in precise geometric shapes, is added an idea of "delirante" space (from lira = border, therefore de-lirare means to go beyond the border), says the philosopher Cacciari (2004). But for the the city "delirare" is essential its empathy in welcoming the different. So, over time, the shape of the city does not depend on top-down relationships between the prince and the designer, but tends to be shaped on the basis of collaborative practices fueled by feedback. This raises a question: if the web is the new arena in which civitas is practiced (a topic dear to Paul Virilio), who will govern the thinkering developing in this arena?;
2. what is the city made of? Over time we have gone from a city explained through its matter to a city composed of matter, energy, connectivity, with an unscheduled process, in search of saving limited resources such as matter and energy, in favor of the use of unlimited resources (connectivity), in the hope of decreasing impact, costs and increasing the knowledge rate. The largely random result is the transition from a city composed of "passive" elements to a proactive city, in which the idea of the border is replaced by that of ubiquity, where the machines that man uses are always more miniaturized, until they are incorporated into the human body.

The chips, the computer technological components, the net, at first was incorporated in the machine, to develop urban ubiquitous infrastructures, connecting people, community and things, with the aim of encouraging more democratic relationship in the process of urban evolution.

Today man is becoming a complex artifact, resulting for the symbiosis between its original natural dimension and the incorporation of bio and nanotools. This is a transitory state of the project of massive replacement of men with robots, which, led by a small number of large companies, distorts the meaning of human beings, putting the values of our civilization in discussion at the root. The long time of evolution seems to have produced the overcoming of the human value in favor of the robotic machine in the service of a restricted economic élites;

3. who "idea" the city? The route goes from the city of the medieval "maestri comacini" (magisters "cum machina"), to the engineers and architects of the industrial revolution era, to which are added the biologists and statisticians (in the second industrial revolution), now integrated by philosophers, mathematicians, neuro-anatomists, neurophysiologists, psychologists, ecologists, anthropologists, and cyberneticians. The expected result of this great panel of knowledge was the "city of convergences," but on the contrary we see the emergence of a "City Brain" aimed at citizen surveillance (Zuboff), or a babelic confusion of languages and tools due to the cognitive asymmetries generated by the expansion of the urban "thinkering;"
4. what are the driving forces? The dance of the city was guided by the war that marked its morphology, with the walls, the segmentation of space from the era of the nations, the control of the relational flows of the Smart City. Over time, this force has been accompanied by an "angelic" vision, advocated by cyberneticians, according to which citizens' relations are absolutely immaterial regardless of the needs of the body and physical relationships.

History has taught us how the evolution of the relationship between man, machine, and space is unpredictable.

The example of the nanomolecular machine intuited by Richard Feynman at the end of the 1950s is worth asking: what will this machine be for? His witty answer is: perhaps to make mites travel in human arteries.

About 60 years later in 2016, the chemists Sauvage, Stoddart and Feringa were awarded the Nobel Prize for their research on nanomachines, inspired by Feynman's intuition. It will serve to transport nano instruments (for example medical) inside the human body (Fig. 6).

In the same 60 years the issue was first studied by the US Department of Defense then by large companies such as Amazon and Tesla, to develop tools for a migration to Mars. Who will choose whether this innovation will be directed toward human care, space tourism, or forced extraterrestrial mass migration?

Rifkin maintains that rather than being directed toward processes of domination, be they economic or military, the technique should be directed toward the development of empathy, therefore the current exponential growth of technology, accompanied by the delirium of the current Babelic city, should be compensated by the

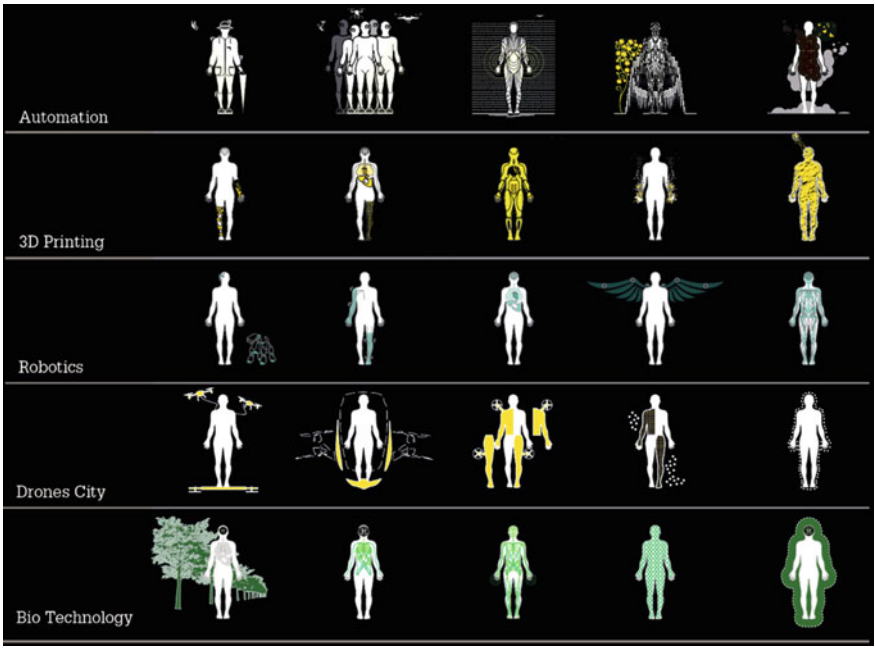

Fig. 6 Winy Maas robotic city: man incorporating a multiplicity of machines

return to the pax romana, in which the urbs (be it material or immaterial) will be accompanied to a civitas based on the value of welcome.

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