Living in Living Cities

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Abstract

This paper presents an overview of current and potential applications of living technology to urban problems. Living technology can be described as technology that exhibits the core features of living systems. These features can be useful to solve dynamic problems. In particular, urban problems concerning mobility, logistics, telecommunications, governance, safety, sustainability, and society and culture are presented, while solutions involving living technology are reviewed. A methodology for developing living technology is mentioned, while self-organizing traffic lights are used as a case study of the benefits of urban living technology. Finally, the usefulness of describing cities as living systems is discussed.
Keywords: living technology, urbanism, adaptation, robustness, learning, self-organization.

1 Urban Advantages and Disadvantages

More than half of the world population lives in cities [29]. With 180,000 people moving to cities every day [76], urban population is expected to grow, reaching 70% of the global population by 2050 [25, 103].

There are several advantages of urban settlements, such as less energetic requirements per capita, higher incomes, innovation, and productivity [63, 21, 20]. In spite of—or perhaps because of—being highly attractive for people, modern cities also face several problems, such as mobility, crime, disease, pollution, and other social problems.

There have been several proposals concerning every urban problem, with different degrees of success. There are cities where the major problem might be mobility (Mexico City, Beijing [64]), safety (Ciudad Juárez, Baghdad), unemployment (Detroit, Madrid), segregation (Chicago, Pretoria), traffic accidents (El Cairo, Dar-es-Salaam), or lack of infrastructure (Lagos, Kabul). Since there are different causes for different problems, there will be no single solution for all urban problems: several solutions have to be explored in parallel.

Urban planning has been guiding the development of cities for decades, at least in developed countries. Planning is certainly useful: it is better to deal with situations before they become problematic. However, urban planning has been rigid so far: how can future requirements be predicted as cities grow and embrace new technologies and customs? Just like a century ago cities were not planned to use cars as major means of transportation, cities cannot be planned now for their requirements of the next fifty years.

The limitations of urban prediction are due to the complexity of cities [58, 72, 52]. Complexity implies that the components of a system are not separable. This lack of separability is due to relevant interactions between components: The future state of components is
co-determined by interactions, which cannot be enumerated, ordered, or predicted. Thus, prediction from initial and boundary conditions is limited.

Cities can usefully be described as complex systems [99, 12, 13], since their components interact and co-determine their future. Thus, urban planning is limited by the very nature of their complexity. This does not imply that general properties of cities cannot be estimated, but that precise prediction is hopeless. To complement this lack of prediction, living technology can serve cities by providing a greater degree of adaptability and robustness.

In the next section, an overview of living technology and its properties is given. Section 3 provides an extensive (although non-exhaustive) description of urban problems and current and potential solutions offered by living technology. In particular, problems in mobility, logistics, telecommunications, governance, safety, sustainability, and society and culture are discussed. Section 4 offers guidelines to develop urban living technology, using self-organizing traffic lights as a case study. The paper concludes with a discussion on the usefulness of describing cities as living systems.

2 Living Technology

The term “living technology” has been used to describe technology that is based on the core features of living systems [17]. Living technology is adaptive, learning, evolving, robust, autonomous, self-repairing, and self-reproducing.

Adaptation [74, 75] can be described as a useful change in a system in response to changes in its environment [47, p.19]. Living systems are constantly adapting because their environment is dynamic. Adaptive technology is necessary where problems are dynamic. Certainly, there are different degrees of adaptation: a thermostat adapts only to changes of temperature, while an autonomous car has to adapt to changes in roads, traffic states, other vehicles, behavior of drivers, etc.

Learning and evolution can be seen as a second order adaptation, since they imply a
permanent change in a system. In other words, after learning or evolution, a system will respond in a different way to similar circumstances. Learning and evolution occur at different timescales: learning is a type of adaptation within a lifetime, while evolution is a type of adaptation across generations. Learning and evolving technologies are useful because they can adapt to novel circumstances. With these properties, the same system will be able to function in a broader range of situations. This increases the potential variety and complexity that the system can cope with [7, 10, 54].

A system can be said to be robust if it continues to function in the face of perturbations [117]. Robustness—also called resilience—is prevalent in living systems and desired in technology [115, 77], as it complements adaptation by allowing a system to “survive” changes in the environment before it can adapt to them. Robustness and adaptation are deeply interrelated, since they are different ways to cope with unpredictable environments. Robustness is passive (changes are resisted by the system), while adaptation is active (changes cause a reaction in the system). Robustness can be promoted by different properties [56], such as modularity [108, 118, 107, 27, 98], degeneracy [39, 42, 116, 121], and redundancy [59].

Autonomy [11, 90, 82] implies a certain independence of a system from its environment. Adaptation and robustness are requirements for autonomy, since they enable a system to withstand perturbations. Additionally, the autonomy of a system implies a certain degree of control over its own production [114, 87] and behavior [48]. Living systems have a high degree of autonomy. Technology has a tendency to become more and more autonomous of humans: from robots [18] to trading algorithms in stock markets [33]. This enables technology to respond to changes at faster rates. However, autonomous technology is also generating faster changes that affect other technologies.

Self-repair and self-reproduction can be seen as particular cases of self-organization [57]. Almost any system can be said to be self-organizing [8]. However, it is useful to describe a system as self-organizing when one is interested in relating how the interactions of elements affect the global properties of a system. This can be applied to living systems at several
scales. For technology, self-organization can be used as an approach to build adaptive and robust systems [47]: interactions are designed so that elements find solutions by themselves. Thus, systems can adapt constantly to changes in their environment.

There cannot be a sharp distinction between non-living and living technology (just as there cannot be a sharp distinction between non-living and living systems). Nevertheless, it can be said that technology will be “more living” as it has more and more of the core properties of living systems.

Living technology can be distinguished as primary or secondary [17, p. 91]. Primary living technology is constructed from non-living components, while secondary living technology depends on living properties already present in its elements. Cities are secondary living technology, since living systems (humans, animals, plants, bacteria) are part of urban spaces. Nevertheless, the non-living components of cities have been acquiring with technology certain aspects of living systems, as mixed networks of soft, hard, and wet ALife [17, p. 92].

3 Solutions for Urban Problems

Cities have been described metaphorically as organisms, e.g. [31, 110]: they grow, have a metabolism, an internal organization, transportation networks of matter, energy, and information, and telecommunications have been characterized as “nervous systems”. Cities can also be seen as technology. However, Lynch [86] argued that descriptions of modern cities as living organisms or as machines are inadequate. Still, the promise of living technology towards resolving urban problems and thus transforming the nature of cities was not yet considered three decades ago. Moreover, Batty [14] has recently argued that the scientific study of cities is transitioning “from thinking of ‘cities as machines’ to ‘cities as organisms’”.

Bettencourt et al. [21] discovered that—in spite of several similarities—various properties of cities belong to different universality classes than those of biological organisms. Neverthe-
less, similar to living organisms, cities are constantly adapting [20]. In any case, this paper is not focussed on deciding whether cities are usefully described as living systems or not, but on exploring the use of living technology to solve urban problems.

Traditional approaches are efficient for stationary problems, i.e. a solution is found, implemented, and the problem is solved. However, most urban problems are non-stationary [55]: population changes with years, opinions can change within days, energy, resource, and waste requirements change with the seasons and with the hours of the day, traffic changes every second. Not only there are changes occurring constantly in urban spaces, but these occur at different scales. Solutions to these problems have to be robust and adapt, matching the scales at which changes take place [47, 53].

Since urban problems are dynamic, urban technology has to find new solutions as problem changes by adapting, learning, and evolving. Living technology can offer this type of solutions [88, 2]. Moreover, cities have been invaded by information technology [81], becoming a mesh of sensors, actuators, and controllers, exploiting the combined abilities of citizens and technology.

Biourbanism [122] has already proposed a similar path, looking at interdependencies between all the components of urban systems, focussing on sustainability and ecology. Biourbanism proposes the use of technologies that are closer to biology with the aim of having a reduced impact on the environment.

Information technology (IT) is bringing several properties of living systems to urban spaces [81]. IBM’s smart cities program aims at solving some urban problems with the aid of IT [35, 66]. The FuturICT european flagship project [70] proposes the integration of techniques from several disciplines to solve global problems, many of them urban. The Earth 2.0 project\(^1\) is also proposed at a global scale, using IT to build more adaptive and sustainable global and urban systems. The organic computing paradigm [91] focusses on information processing systems with properties of living systems. Organic systems can be

\(^1\)http://earth2hub.com

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considered as living technology.

In the next subsections, several urban problems and potential solutions with living technology are presented.

3.1 Mobility

The movement of people and goods is one of the major urban problems. It requires expensive infrastructure (roads, rails, ports, stations, bridges, vehicles, fuel, signalization). When mobility is inefficient or saturated, people lose time and money, gain stress, and more pollution is generated. Overall, the quality of life is reduced when mobility is limited or not efficient. There are several problems within urban mobility, so there will be no single solution for all of them [26]. At least eight interrelated aspects of urban mobility can be identified:

Transportation requirements. There is no mobility problem if people and goods do not have to be displaced. It is not possible for everyone to study, work and grow produce at home, but many actions can be taken to reduce the need of moving people and merchandise, i.e. the mobility demand.

Scheduling. Congestion occurs when there are too many people in the same place at the same time. If people can transport themselves with more flexible schedules, then the demand of rush hours can dissipate over longer periods of time.

Quantity. Too many vehicles or people saturate roads and public transportation systems. To reduce this, some cities use measures to demotivate use of private vehicles, such as high taxes, congestion charges, and limited parking. More flexible approaches to reduce vehicle quantity are carpooling and carsharing [44], e.g. Zipcar and Buzzcar.

Capacity. Building more and broader freeways, bike lanes, public transportation systems and efficient traffic lights increases the capacity of urban mobility. An increased capacity can be expensive, although technology can allow for increases in capacity at reduced costs.
Behavior. Inadequate behavior of drivers or passengers can lead to delays in transportation. Examples for drivers include speeding, compulsive lane changing, and texting while driving. Examples for passengers include pushing and blocking, which can occur in different circumstances. Potential interventions for restricting inadequate behaviors and promoting positive behaviors include education campaigns, fines, real-time information and social participation [109].

Infrastructure and technology. Infrastructure such as freeways, public transportation, bike lanes, and vehicle sharing systems can contribute to improve mobility. Technology can complement infrastructure, by enhancing its capacity. For example, traffic sensors can be used to coordinate traffic lights, avoid traffic jams, and suggest alternative routes.

Society. In most societies, owning a car implies prestige, reflecting certain economic success. However, people are becoming so successful that roads are saturated. In several cities, people naturally prefer alternative modes of transport. With a social acceptance of car-owning alternatives, it will become easier to balance different modes of transportation farther from private cars.

Planning and regulation. Even when urban planning has limitations, cities suffer when there is no urban planning at all. In many cities this is complicated because politicians and not urbanists make the decisions on urban projects. Also, some cities do have planning and projects, but there is no enforcement nor regulation. Thus, plans never materialize and projects never are implemented.

There are different actions that can be taken to improve different aspects of the eight factors mentioned above. For example, more capacity can be built. But if the quantity increases faster than the capacity, the improvement will be severely limited and problems will not be solved. In general, all of the eight factors have to be considered in parallel to
improve urban mobility. In the next sections, examples of potential applications of living technology to address different problems in urban mobility are presented.

3.1.1 Public Transportation

When thousands or even millions of people have to move in urban areas through similar routes, mass transit becomes a better alternative than private motorized vehicles. Metro, bus rapid transit (BRT), trams, buses, and trains have been used since the nineteenth century for this purpose.

According to theory, passengers arriving randomly at stations wait the least when headways—the temporal interval between vehicles—are equal [120]. However, this configuration is always unstable, for all public transportation systems [60]. Random arrivals at stations will cause some stations to be busier than others. When a vehicle arrives at a busy station, it might be slightly delayed, increasing the headway with the vehicle ahead and reducing the headway with the vehicle behind. The longer headway might cause further delays at the next station, increasing even more the headway with the vehicle ahead and decreasing even more the headway with the vehicle behind. This equal headway instability leads to the formation of “platoons” of vehicles that affect negatively the service, leading to long delays for passengers. There have been several approaches for dealing with equal headway instability in particular transportation systems [113].

Recently, it was found that transportation theory had misguided assumptions for decades [53], namely that vehicles along a route will have the same travel time, thus developing methods that aim at maintaining equal headways, reducing waiting times for passengers at stations. However, in order to maintain equal headways, some vehicles have to idle at stations. A self-organizing method was proposed [53], where the equal headways are relaxed and even when passengers wait more at stations, the total travel times are reduced by a slower-is-faster effect [71, 69]. The proposed method uses “antiphеромones” to make local decisions depending on neighboring vehicles and passenger demands at current stations, adapting to
changing demands and delivering a “supraoptimal” performance.

3.1.2 Traffic Lights

The coordination of traffic lights is an exponential-complete problem [95, 83]. Moreover, the traffic configuration changes constantly, as demands at intersections vary at the seconds scale. For this reason, fixed, optimizing approaches are limited for traffic light control [61].

Adaptive methods, some of which are biologically-inspired, have been proposed to regulate traffic lights. Faieta and Huberman [41] proposed an algorithm inspired in firefly synchronization, while Ohira [94] proposed a controller based on an analogy with neural networks.

Self-organizing traffic lights [46, 68, 30, 83, 100, 62, 32] can adapt to the local traffic demand, leading to an emergent and robust global coordination of traffic lights. Some of these methods are in the process of being implemented [84], reporting considerable improvements in waiting times for cars, pedestrians, and public transport. This leads to economic, energetic, environmental, and social savings. These are further discussed as a case study in Section 4.1.

3.1.3 Real-time Information

The commercialization of GPS devices allowed drivers to query for the shortest route to their destination. However, once several people were using GPS, shortest routes were saturated, since everyone was advised to follow them. Shorter but not fastest. Real-time information—available for decades in radio traffic reports—can help drivers adapt their route according to the current traffic situation. A limitation of radio reports is that they are broadcasted: all drivers get the same information, most of which might not be relevant, and drivers cannot demand for particular information. This scenario has changed in recent years, with applications such as Google Maps\(^2\) and Waze\(^3\), which provide real time traffic information.

\(^2\)http://maps.google.com
\(^3\)http://www.waze.com
on demand.

A key element of real-time information systems consists of sensors [28, 36]. Once traffic states are detected, broadcasting or making them available is relatively straightforward. Since there are different types of sensors (fixed, mobile), sensor integration [101] is a relevant problem to obtain useful information.

Intervehicle communication can provide useful real-time local information, which can be exploited to adapt to dynamic traffic states and improve traffic flow [80].

Real-time information for public transportation systems can also help passengers to adapt their routes more efficiently, and even their behavior [60].

3.2 Logistics

Biologistics [67] notes that the organization, coordination and optimization of various material flows is not restricted to artificial systems, but that living systems also have to deal with material flows. Moreover, living systems can handle material flows efficiently, adaptively, robustly, and learn from past experiences. Thus, with biological inspiration, using principles of modularity, self-assembly, self-organization, and decentralized coordination, artificial logistic systems can be designed that can adapt efficiently to changes of demand.

A drawback to traditional approaches in logistics is that the supplies and demands for different goods are dynamic and unpredictable. This demands approaches where systems can adapt to changing demands at the same scale at which changes occur. For example, swarm intelligence [24, 79, 112] has been applied to several problems in logistics [111].

Computationally, algorithms inspired by swarms or neurons are equivalent [50], since they function at multiple scales, allowing them to compute solutions to problems at a faster scale and at the same time adapt to changes in problems at a slower scale. This is a desired property in logistics and many other areas.
3.3 Telecommunications

A distinction can be made between synchronous and asynchronous communication [34, 49]. IT has reduced delays of information transmission, allowing for technologies with faster response rates. Moreover, IT has made it possible to shift from broadcasted information to information on demand. Availability of information is a requirement for living urban technology, since relevant information is required in order to adapt, learn, and evolve. This was already illustrated in Section 3.1.3.

Telecommunications have an essential role towards the use of living technologies in urban spaces. Not only for information transmission among citizens, but also among devices and systems [102]. For this purpose, several approaches have been proposed to build adaptive, flexible and robust telecommunication networks [37, 38]. These networks are becoming so complex and operate at such speeds, that their technology can only function efficiently exhibiting the properties of living systems.

Telecommunication systems are relevant not only for transmission of information, but enable other uses of living technology in urban spaces, such as governance [97].

3.4 Governance

Bureaucracies are often seen as rigid, slow, and inefficient. Living technology can enable the adaptive transmission of relevant information to govern cities [49]. Any adaptive system requires sensors to be able to detect when changes are required. An obstacle in governance is that sensors are rather poor to allow governments to make informed decisions. Simply there is no infrastructure to detect what are the requirements of citizens. For example, India is connecting 250,000 local governments (Panchayats) to deliver and obtain information to and from citizens [93].

Sensors are important but not the only aspect where changes are being made. Technology can also be used to make better collective decisions [104, 105]. This possibility enables societies to respond adaptively to different situations. This also helps governments to better
administer cities.

Governments have also been making their data publicly available, so that citizens can use this information in novel ways [22]. Opening data and information enables many potential applications. Also data created by citizens can be useful. For example, after the 2010 Haiti earthquake, people used OpenStreetMap\(^4\) to improve maps and assist rescue and humanitarian aid efforts, identifying via satellite pictures collapsed buildings, refugee camps, and other damages.

The availability and processing of masses of urban data open the potential to governments that adapt constantly to changes in demand of their citizens. Moreover, they allow an increased citizen participation in governance, slowly fading the differences between governors and the governed. An extreme democracy can be reached when the opinion of every citizen has the same weight on any political affair. This would be achieved only with living technology, since such a system would have to adapt constantly to the changes in the population.

### 3.5 Safety

In a similar way that living technology can improve governments, it can improve urban safety. On the one hand, prompt and adaptive response to natural and artificial catastrophes is facilitated. On the other hand, an urban mesh of sensors can increase public safety by monitoring public and private spaces, thus increasing citizen accountability. Simply having cameras to detect traffic infractions enforces people to comply with traffic rules, which—if designed properly—lead to increased road safety.

Artificial immune systems (AIS) have been proposed to to prevent intrusions in networked systems [73]. AIS exhibit properties of their biological counterparts: they are distributed, robust, dynamic, diverse and adaptive. Since intrusions are seldom repeated, security systems have to be flexible enough to adapt and respond to novel situations constantly.

\(^4\)http://www.openstreetmap.org/
If used properly, living technology could also reduce crime rates. Having an effective police is not a solution for urban crime, since its causes seem to lie in unemployment, lack of opportunities, social influence, and several other factors [119]. Nevertheless, crime prevention is necessary, and it will be more effective if it exhibits properties of living systems [40], since changing circumstances, trends and behaviors open constantly new niches for crime. Thus, an effective crime prevention has to adapt to these changes, to learn from previous experiences, and to be robust in the process. It might be just a coincidence, but life has become safer as technology has evolved [96]. The causal relations between technology and safety have yet to be explored, but this trend probably will continue, increasing safety as technology becomes “more living”.

3.6 Sustainability

Sustainability is the capacity to endure. For cities, sustainability involves not only environmental relations, but also economical and social. Material and energetic resources are required to “fuel” cities, as well as economic and social benefits to attract and sustain citizens.

Concerning material sustainability, pollution has to be considered. If there is less waste produced, then the complexity of waste management will be reduced. Cleaner and more efficient technologies can help in this direction. For example, if traffic flow is more efficient, less pollution will be produced by motor vehicles. Also, local production reduces transportation and transmission burdens, but the cost of production might be higher. Thus, a balance between mass production (cheaper to produce but distribution required) and local production (more costly to produce, cheaper to distribute) should be sought. Nevertheless, living technology can contribute to both reducing the cost of local production and to increase the efficiency of distribution (See Section 3.2).

Synthetic biology [19] (wet second-order living technology) is promising for producing cleaner fuels [85], as well as technology to reduce or prevent pollution, such as buildings that
absorb carbon dioxide and bioluminescent trees that do not require electricity [4].

The efficient and adaptive production and distribution of energy, as envisioned by the concept of a “smart grid” [45, 3] is similar to other urban problems: there is a varying demand, as well as a varying production, which ideally should match the demand. Living technology can certainly benefit energy grids, coordinating local generation of energy and distributing it “on demand”.

Another application of living technology is the dynamic regulation of rainwater to collect water and prevent floods, where catchment systems react on the weather forecasts and water supply levels [89, 106].

A sustainable economy should produce more than what it consumes. Moreover, it has to accommodate employments, opportunities, and pensions for dynamic populations (aging in some countries, growing fast in others). W. Brian Arthur has recently described “the second economy” [5], based on information technology, where processes are interacting, adapting, and having an effect on the “physical” economy. Arthur mentions that the second economy has properties of living systems, since digital devices and processes are starting to sense, compute, make decisions, and perform actions adaptively and independently of humans.

Businesses and enterprises also have to develop and acquire living technology, since the demands of the markets are changing constantly and at increasing speeds. Organizations that are adaptive and robust will have better chances of enduring unpredictable changes in the economy. Moreover, urban living technology is itself a novel business niche [6].

Living technology can also have a positive effect in the social aspects of urban spaces. Safety was already mentioned, but in general living technology can help citizens to be more cooperative. Taking the example of driving, in some cases it might be beneficial for a driver to drive in such a way that affects negatively other drivers, tempting them to do the same. When a few drivers follow this behavior, the traffic becomes worse for everybody, including those that attempt to get a benefit. Cooperation has been extensively studied with game theory [9, 92]. Living technology can provide several alternatives to promote cooperation.
On the one hand, those who do not cooperate could be punished automatically. On the other hand, those who do cooperate could be rewarded. Moreover, living technology could help change situations in such a way that it will be beneficial for individuals to behave in such a way that is beneficial for the society as well. In other words, if the payoff for cooperating is always the highest, there will be no social dilemmas: everybody will selfishly cooperate.

3.7 Society and Culture

One example of a social benefit is given with innovation, which is already promoted by cities [21]. Can living technology accelerate innovation in cities? It seems that the answer is affirmative, at least indirectly: if living technology can solve at least some of the urban problems mentioned above, it will increase the attractiveness of cities to citizens. Moreover, it will increase the “carrying capacity” of sustainable cities. Since larger cities tend to be more innovative, and living technology would allow cities to grow even more, it can be concluded that such “living cities” will have an increased innovation rate. And innovation not only in science and technology, but in culture, education, and art as well.

Since IT and the Internet are reducing the burden of transportation, people are exchanging information remotely and globally, overflowing the benefits of urbanization across cities.

Social media—such as Twitter and Facebook—are transforming and facilitating social interactions. For example, “Social moods” have been detected [23]. Technology over social networks could potentially be used to steer social behavior, for example preventing unhealthy habits and promoting healthy ones [51].

4 How to do it?

In the previous section, examples of existing and potential urban living technologies were mentioned. This section will focus on how living technology can be developed for urban problems in general.
Recently, a methodology was developed for designing and controlling systems that require to be adaptive and robust using the concept of self-organization [47]. Instead of designing a system to solve a problem that is changing constantly, with self-organizing systems components are designed so that they find solutions by interacting among themselves. This allows them to *autonomously evolve, learn* and *adapt* to changes in the problem and to continue functioning in a *robust* way. The methodology focuses on identifying the nature of interactions and eliminate or reduce negative interactions (“friction”) and promote positive interactions (“synergy” [65]). Interaction improvement always leads to system performance improvement [47]. This approach is useful when the problem or situation is unknown, undefined, or dynamic.

The methodology is only one of several that have been proposed with similar aims in the literature. A review and comparison can be found in [43]. Engineering methodologies that embrace complexity are promising for developing living technology. This is because they offer frameworks where artificial systems with the properties of living systems can be developed.

In the next subsection, traffic lights are used as a case study where living technology based on self-organization clearly outperforms traditional approaches.

### 4.1 A case study: self-organizing traffic lights

City traffic is complex (vehicles interact and affect each other) and chaotic (small changes in a traffic state lead to large differences). This complexity and sensitivity to initial conditions considerably limits the predictability of city traffic beyond a couple of minutes. Nevertheless, traditional approaches for coordinating traffic lights aim at predicting expected traffic flows, and optimizing a problem that is changing every second. Moreover, as mentioned above, traffic light coordination is an EXP-complete problem, i.e. it is intractable.

We have made several simulation studies of self-organizing traffic lights [46, 30, 61, 62], comparing them with traditional traffic light control methods. On a realistic simulation
of a Brussels avenue, our method reduced average waiting times by 50% [30]. This leads to considerable savings in fuel and greenhouse gas emissions. An extrapolation of these results for Mexico City would imply savings of 400 million liters of fuel and one million tons of CO2 per year, with an implementation cost of twenty million dollars for one thousand intersections. On a more abstract simulation, we have shown that self-organization can lead the system close to the theoretically optimal velocity and flux curves for varying densities [62], while traditional methods are far from the optimal curves, especially for high densities.

Self-organizing traffic lights can be considered as living technology because they autonomously adapt immediately to changes in demand and are robust to parameter variations and intersection failures. Solutions are not predefined. Simple rules allow intersections to be demand-driven at low densities and space-driven at high densities. In this way, traffic lights coordinate “stigmergically” by demand or by space. Following the methodology [47], this method promotes positive interactions between intersections and vehicles, leading to a near-optimal global efficiency. Traditional coordination methods are limited in several ways: they can coordinate only two directions (e.g. southbound and eastbound), they are optimized for expected flows and not for incoming vehicles, and they are optimized for fixed densities. They do not adapt (same cycles independently on demand) and fail to be robust (a single intersection failure can cause a bottleneck that will percolate across a city). Living technology offers several advantages in the case of traffic light coordination. Benefits should not be too different for other urban problems.

5 Beyond the Metaphor: Towards Living Cities

Cities will offer a higher quality of life if they exhibit the properties of livings systems. After listing several current and potential urban living technologies, one can ask to what extent speaking about living cities is a mere metaphor and to what extent cities are usefully described as living systems.
Living systems are constantly adapting, learning and evolving because their environment is always changing at different timescales. Living systems also require to be robust to endure unforeseen perturbations. Efficient cities have to do the same: their demands change constantly at different scales, so they must adapt, learn and evolve in a robust fashion in order to endure. Cities are not physically similar to living systems (no DNA, no membranes), but functionally, they should exhibit the same properties. From a materialist point of view, it makes no sense to speak about living cities. However, from a functionalist point of view, it is very relevant to speak about the relationships between living systems, artificial life, living technology, and urban systems. This is because the properties of living systems (natural or artificial) can be exploited to solve urban problems, making cities more adaptive and robust.

If a notion of life based on entropy or information is used [1, 48], then one can even measure to what extent different cities can be considered to be alive, with a continuous transition between non-living and living systems [16]. In non-technical terms, if a city has a sufficient control over its own production, endowing it with a certain autonomy and integrity, then it can be usefully described as a living system. Living technology has been contributing to the increase of the “liveness” of cities, as it was shown by the examples presented in this paper. Moreover, the study of “living cities” is related to at least one of the open problems in artificial life [15]: To determine whether fundamentally novel living organizations can exist.

Technology has always evolved [78], but with the aid of humans for most of its history. As living technology is developed, technology will be able not only to be more adaptive and robust, but to evolve by itself in directions that we cannot foresee. What can be said is that the integration between technology and living systems—including humans—will increase. Living cities will be the outcome of this integration.

Will solutions to urban problems using living technology bring new problems? Since predictability is limited, most probably new problems will arise. Nevertheless, we can always transform problems into opportunities. How? By deciding to do something about them.
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