Enhancing the integration of Nature-Based Solutions in cities through digital technologies

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Abstract. During the last decades a growing awareness about the effects of pollution on our planet and its inhabitants has led to a demand for a new environmental sensitivity in urban planning. Nature-Based Solutions have the potential to enhance the liveability and prosperity of cities, providing ecosystems services (Millennium Ecosystems Assessment, 2005).
The paper explores pathways towards a progressive knowledge construction to shape a future in which NBS are largely integrated in our buildings and public space thanks to the use of digital technologies and design, transforming our cities into healthy, productive and collaborative environments.

Keywords: Nature-based solutions; Digital technologies; Advanced manufacturing; Food; Mushrooms.

Building with nature

Over the past decades, European cities have strengthened their economy, efficiency and liveability through the implementation of new and innovative planning paradigms, such as the "Urban Regeneration" and the "Smart City" models. However, they still face major problems, such as pollution, rising inequities and unemployment. Innovative models to overcome these problems, therefore, need to be developed, adopting a new transdisciplinary approach, which takes into consideration new ecological and social approaches, innovative business models, latest scientific and technological findings.

Nature-Based Solutions (NBS) represent a way to address urban issues with a holistic approach. They are defined by the European Commission as «living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits» (European Commission, 2015). NBS are addressing societal challenges by providing multiple ecosystem services. These services, according to the Millennium Ecosystems Assessment (2005), can be divided into four main categories: life support, such as soil formation and oxygen production; procurement, such as the production of food, drinking water, row materials or fuel; regulation, such as climate control and tidal waves, water purification, pollination; and cultural values, including aesthetic, educational and recreational values.

Building with nature, taking advantage of the services that living systems can provide, is a planning model that has been developed over the last fifty years and is gaining increasing importance today. The idea of environmental interdependency started to be defined in the modern scientific literature during the 1970s. However, in the 19th century, some scientists already mentioned it: at the beginning of the 19th century, the Prussian naturalist Alexander von Humboldt described the earth as a living organism where everything is connected (Wulf, 2017), and the Russian botanist Kliment Timiryazev wrote in the late 19th century that plants are the link between the Sun's energy and that of Earth (Mancuso *et al.*, 2018). The Gaia hypothesis, developed in 1979 by James Lovelock, is heir to the visionary spirit of Humboldt (Sampedro, 2016). It states that the earth, and more in detail its biosphere, is a living organism where the oceans, the seas, the atmosphere, the earth's crust and all the other geophysical components remain in conditions suitable for the presence of life thanks to the behaviour and action of living organisms, plants and animals (Lovelock, 1979). By the 1990s it was generally understood that a more systematic approach would have promoted the conservation, restoration and sustainable management of ecosystems (Millennium Ecosystem Assessment, 2005). During the late 2000s, the term 'Nature-Based Solutions' emerged, marking a shift in the planning perspective: human kind is not only the passive beneficiary of the benefits that nature can bring, but can also proactively protect, manage and restore natural ecosystems contributing to address major societal challenges (IUCN, 2016). Currently one of the main sources of knowledge on NBS are the international research projects supported by the European Commission under the programme Horizon2020[1]. They are targeted at developing strategies to implement NBS in cities, assessing the ecosystem services; guidelines and platforms gathering the knowledge acquired are under development (or in some cases already available) to allow their replicability, assessing climatic, technical, financial and urban planning aspects among others.

Advanced Nature-Based Solutions design

At the turn of the century, the irruption of the digital age and of a new interactive logic contributed to strengthen an environmentally conscious perspective through optimisation of the processes (Gausa, 2019).

In the field of Nature-Based Solutions advances in digital technologies open new chances to facilitate the integration of NBS in the urban environment increasing the number and the quality of the ecosystem services provided. Digital technologies, such as simulation tools and parametric design software, open to the possibility to develop passive environments optimised to support living organisms, simulating the system performances during the design phase, while digital fabrication allows for the production of non-standardised design systems specifically tailored for local needs.

We are now experiencing a big shift, starting to understand architecture as an integrated system of inert and biological matter, a scaffold for inhabitation, not only for humans, but also for an entire surrounding biota. In this framework advanced software is helping us to predict very complex growing and emerging systems, and it is starting to open the doors to a type of design sophistication that we did not deal with before (Cruz, 2019).

We are starting to work on cities with a new multidisciplinary approach, at the intersection of design, technology and biology. Since this type of research is at an early stage of development, currently most of the projects working with this approach are developed in the form of prototypes in academic or research institutes, and presented in exhibitions or expos.

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01 | Production of the project prototype, IAAC, photo by Federica Ciccone

The Advanced Architecture Group (AAG), part of the Institute for Advanced Architecture of Catalonia (IAAC), is developing, within its educational programmes and in the framework of several European Projects, a research on Advanced Nature-Based Solutions aimed at hybridising technologies, urban and natural environment and innovating the solution design and implementation process.

Creative food cycles project

The AAG is developing part of this research within the framework of the Creative Food Cycles (CFC) project, co-funded by the Creative Europe Programme of the European Union. CFC involves 3 partners, the Leibniz University of Hannover, the IAAC, and the University of Genova, and is aimed at capacity building through training and education in the field of architecture, focusing on food sustainability in urban environment. Several activities have been performed within the project, such as workshops, development of project mock-ups, exhibitions and conferences.

The project lays its foundations on the awareness that today we have accessibility to products coming from anywhere in the world, all year round; however, it is questionable whether the quality of these products is healthy, and whether the food chain is sustainable. For instance, food production, distribution and disposal involve a complex set of economic activities, exchanges (digital and physical) and human behaviours that all sharply affect the living conditions of the planet and its inhabitants. It is, therefore, necessary to rethink food systems, focusing, at local level, on their potential to strengthen and eventually restore the environment, the communities and the economy. The project takes into consideration the whole Food Cycle chain: production, distribution, consumption and disposal.

The AAG addresses the first part of the chain, working on digital technologies and NBS for food production.

Educating to develop advanced design projects integrating Nature-Based Solutions

In order to create new knowledge regarding the development of architectural projects designed as passive environments to integrate in the urban environment living systems producing food, the "Creative Urban Farming" workshop was held in May 2019 and the best project was further developed and scaled up in a mock-up that was tested and exhibited at several events.

The projects of the students participating in the workshop had to meet the following questions: how can we integrate food production and distribution in the urban environment, enhancing participatory processes and circular use of available resources? How can new and innovative technologies help to design, develop and implement healthy food production systems for the urban environment? As vegetables are Living / Nature-Based Solutions, can they provide also further ecosystem services while they are growing?

During the workshop the students were working following the "learning by doing" methodology, designing their projects and developing a working prototype (Fig. 1) of their solutions using digital fabrication tools, such as laser cutters and CNC machines. Within the "learning by doing" methodology the production of prototypes is an integral part of the design process, as it allows designers to explore alternatives, test theories and concepts and confirm the performance of a new design system (de Kastelier and Rabagliati, 2012).

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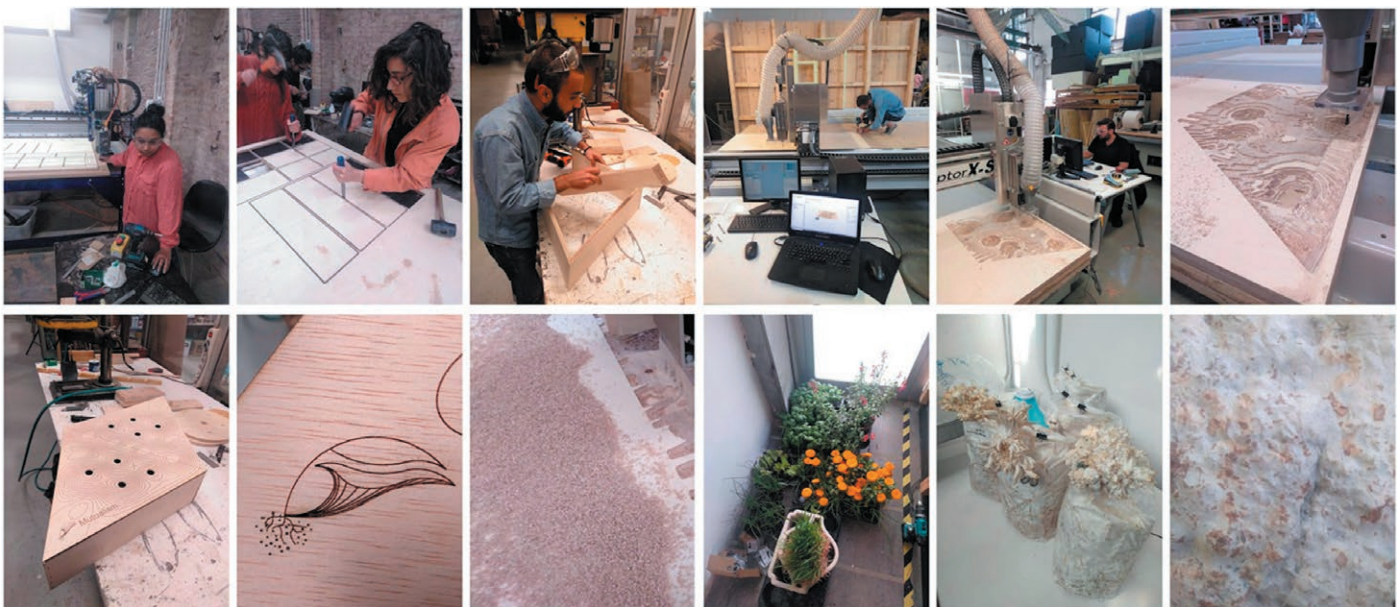

02 | Mutualism external surface, IAAC, photo by Federica Ciccone

03 | Mutualism internal surface, IAAC, photo by Federica Ciccone

04 | Mycoscape project, IAAC, photo by Federica Ciccone

Mutualism project

The students' work that was chosen as the most outstanding in responding to the initial questions is project Mutualism.

The word 'Mutualism' refers to the ecological interaction between two or more species where they both benefit from each other. The collaborative living systems integrated in the project are herbs and Oyster mushrooms: mushrooms need moderate temperatures to grow, and herbs have the potential to mitigate the urban heat island effect. The project consists in a modular pavilion with two sides: the external side, which is exposed to sunlight, is targeted at the growth of edible plants, which narrow down the temperature during the hot season, while the internal side, which is shadowed, is targeted at mushroom growth. The pavilion is an urban infrastructure managed by neighbours: they provide maintenance for the plants and, in exchange, receive the pavilion's products. Neighbourhood coffee grounds are recycled and implied as nutrients to be added to the straw substrate used to grow Oysters mushrooms. The pavilion produces one further output, acoustic panels for the construction industry: while Oysters mushrooms are grown, the straw substrate is converted by the mushrooms' roots into a phono-absorbent resistant material. This can be sold by the neighbours to produce extra income. The herb and mushroom substrate is separated by a shaped surface, which serves to isolate the roots of the plants, that could transfer bacteria affecting the mycelium growth, and to shape the form of the acoustic panels.

The surfaces of both sides are parametrically designed to optimise both mushroom and herb growth conditions: the external surface (Fig. 2) is designed to collect rainwater and to direct it towards the holes in which the plants are placed; the internal surface (Fig. 3) is defined to maximise lighting and reflection to help mushrooms to fruit.

During the workshop, students learned that digital design programs make it possible to develop building systems integrating plants

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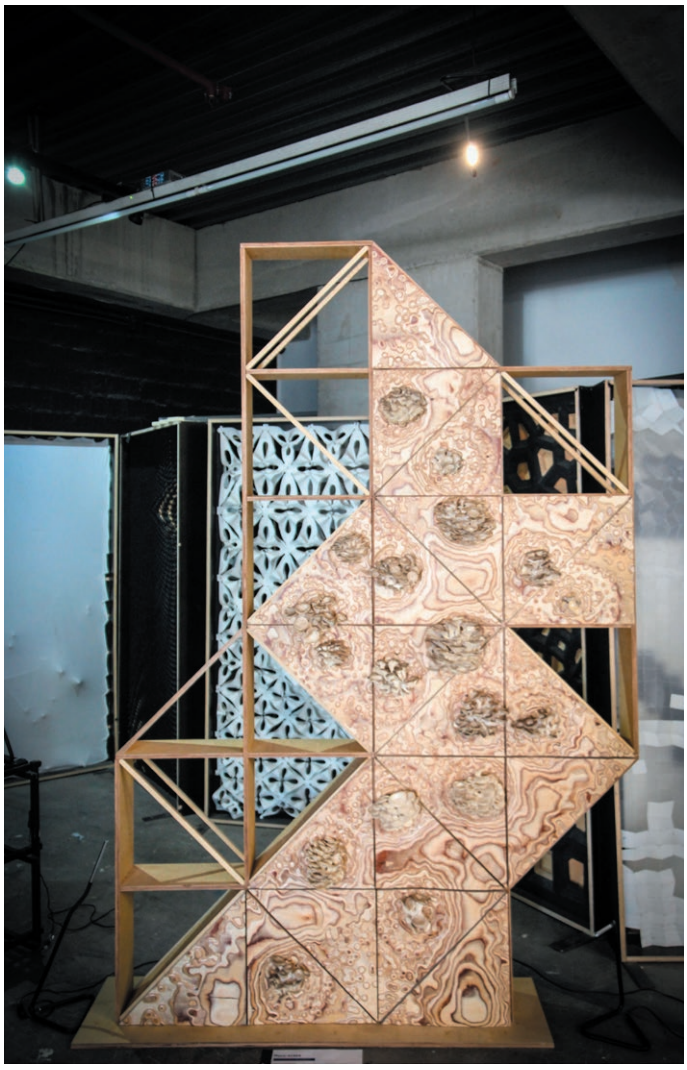

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05 | Mycoscape external surface, IAAC, photo by Federica Ciccone

06 | Mycoscape drawings, IAAC, drawings by Mohamad Atab

07 | Mycoscape external surface detail, IAAC, photo by Federica Ciccone

08 | Vision of the application of Mycoscape to a building facade, IAAC

growth in the urban environment, running simulations to correct and optimise the surface morphology. Moreover, they learned that the shift from analogue towards digital does not only happen in the design stage, but also in the manufacturing and fabrication stages. Milling, cutting, bending and drilling are now processes that are directly driven by a computer code.

Demonstrating advanced design projects implementing Nature-Based Solutions

The Mutualism prototype has been further developed and scaled up into the Mycoscape project (Fig. 4), which consists in a façade modular system integrating the growth of edible mushrooms in the urban environment, producing food and construction materials.

Mycoscape aims at defining innovative design protocols, demonstrating the potential of parametric design and digital fabrication supporting the development and implementation of systems for urban food production, responding to local environmental conditions and making sustainable use of local resources.

The mushroom growth takes place thanks to two systems: the first one consists in triangular modules where the straw substrate and the Oyster mushroom spores are located, and the second one consists in the external surface (Fig. 5) aimed to passively control the parameters that affect mushroom growth, namely temperature, humidity and shade. In order to control these conditions a tree trunk and bark, which are the mushroom's natural habitat, have been studied and mimicked. With the aim of reproducing the microclimate that the tree trunk and bark create, protrusions increasing the thickness of the external surface were distributed along the external surface (1), thus favouring the temperature control of the area where the substrate is placed, and creating shadows on the holes where

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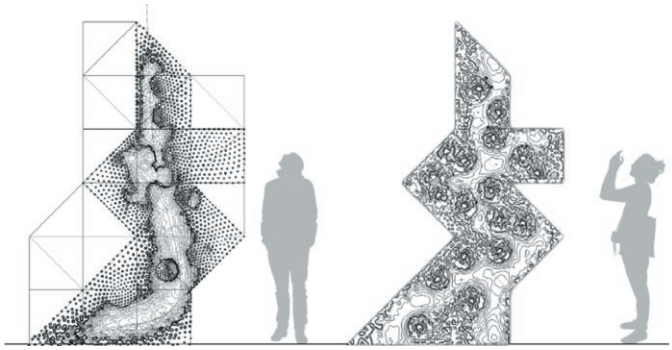

mushrooms fruit and (2) circular elements collecting air humidity during the night and releasing it during the day (Fig. 6 and 7).
The project brings significant improvements to the state of the art in the field of mushroom application in the urban environment. Currently there are two types of applications. The first one is the urban mushroom farm. An outstanding example, focusing on circular economy, is the Mushroom Forest developed in Amsterdam by Jacques Abelman. It consists in vertical tubes in which various types of waste can be inserted to be used as mushroom growing substrate. Existing urban mushroom farms do not make any use of the material produced by the mushrooms and the substrate during the growth process. The second application consists in the development of building materials and home design products with mycelium, the vegetative part of the mushroom. One of the first producers has been the company Ecovative Design, which since 2007 started to commercialise mycelium lamps. Since than several new companies have been established and products developed with mycelium are gaining importance and visibility: the tower 'Hy-Fi', designed by David Benjamin, was exhibited at MoMA in New York, demonstrating the use of mycelium bricks for hi-rise buildings, while the 'Growing Pavilion' presented at the Dutch Design Week 2019 by the Krown Design studio demonstrated the use of mushroom panels for façades. However, producers of mycelium products do not use the mushroom fruits for food proposals. Mutualism brings several improvements to the state of the art: it brings together the production of food and building materials in a unique system, providing two different ecosystem services within one NBS, thus avoiding waste and making the most out of available resources. Moreover, it makes use of design to control environmental parameters connected to mushroom growth, allowing to use urban surfaces as agricultural fields. This new approach has several implications at social and economic level. It allows to envision new forms of hybrid and collaborative economies: for example, municipalities could make available public building façades, citizens could organise themselves in associations to cultivate, as low skills are required, start-ups could create product branding and take care of their commercialisation.
Mycoscape is a proto-environment (Gausa, 2019), which simulates a new collaboration between nature and humans, technology and design, and new relations between city inhabitants (Fig. 8).

Conclusion

Creative Food Cycles project has created capacity and demonstrated the potential of the use of computer aided technology towards the integration of living systems in the urban environment. Bullivant (2006) states that if architects aim to create a responsive environment, they are required to think like designers of operating systems, arguing also that the development of complex, comprehensive and informed design process are fundamental procedures that generate new relations, narratives, potentialities and hybrid forms of [co]existence.

NOTES

[1] The European Commission under the programme Horizon2020 has supported the following projects: EdiCitNet, CLEVER Cities, proGIreg, URBiNAT, CONNECTING Nature, GrowGreen, UrbanGREENUP, UNALAB, CLEARING HOUSE, REGREEN, RECONECT, Operandum, MyBuildingIsGreen, OPPLA, THINK NATURE.

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