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3D printing technologies for a biomimetic landscape design / Rapid prototyping for the renovation of Shkoder's waterfront

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Abstract

The advancement of digitisation has set the foundations for the definition of new economic and cultural assets in different sectors. Among them is the construction industry, which has stood out for having experimented new automation technologies to update and optimise some key stages of the traditional realisation process, with the aim of refining the overall quality of the results. The most widely used systems, which are able to process printable materials following the information given by three-dimensional digital models, allow a range of possible operations, such as the computer-aided motion, installation, subtractive sculpting or additive creation of manufactured elements. In particular, over the last decades the additive construction tools, also known as 3D printing or rapid prototyping, have demonstrated to be efficiently applicable, at any scale, for the elaboration of an innovative design and a simplified realisation methodology, in accordance with the increasing demand of sustainability requirements. 3D printing is therefore a valuable option to help reducing the environmental impact and improving the design morphology of the outputs, in compliance with the local natural peculiarities of a given location on intervention. This article aims to contribute to the debate on the potentials of the most advanced tools to generate a qualitative contribution to territorial regeneration strategies, especially in protected areas, where building constructions or landscape structural projects are prevented. Rapid prototyping is defined here as a repeatable technique to create territorial components in damaged natural frames that need recovery measures, due to the imprint of uncontrolled human activities. Indeed, urbanisation, infrastructure connections, and constructions spreading - in particular when they are not driven by regulatory plans and sustainable land management policies - are the principal reasons for environmental losses, especially in those contexts that are not capable of absorbing the changes to which they are subjected. To substantiate our arguments, a case study is used. It is the city of Shkoder, located in the Albanian shore of the namesake lake and included in the Ramsar List of watersheds to be preserved. The reasons for selecting this case is its complexity: the misuse of the soil in Shkoder's area caused by the human imprint (permeability modification, consumption of the local flora, and pollution) allows frequent floods to run over the city during autumn and winter months causing significant damages and consequently the lowering of the coastal landscape quality. We will argue that 3D printing helps to define new scenarios for recovery projects in wetlands or shoreline zones that change settings due to the variable level of water, by using low-cost, reversible and compatible materials (sand conglomerates, raw clay or reconstructed stones) with the surrounding environment. Following biomimetic design principles, a rapid prototyping technique can be used to create free-form reefs and walking paths, as landscape characterisations when they are exposed, or underwater natural habitats in the event of flooding. The definition of punctual or integrated projects for the renovation of Shkoder's coastal lands, therefore, can be considered as an opportunity to develop a more resilient and adaptive landscape, able to react positively to potential background modifications.

Fig1 / A lagoon area of Shkoder's Lake, in a current state of degradation. The wetland has an unexploited landscape potential because the context lacks of updated territorial policies source / photo by Sara Codarin

The use of 3D printing technology as an opportunity for landscape renovation

Last decades have witnessed the development of digitised technologies in the production sector, from the realisation of design objects to the definition of large-scale components. This trend can be framed within the aspects of the so-called second digital revolution , a change currently taking place in the field of industrial and handicraft manufacture through the possibility of "turning data into things" (Gershenfeld, 2012) by reading the digital data and then processing their spatial characteristics with physical matter.

The most advanced digital tools have caught the interest of companies because of the chance to build prototypes (study models for the elaboration of goods for mass production) in order to enhance and customise their own fabrication chain, goals otherwise unattainable using traditional methods.

Moreover, modern society is developing circular economic models (Lacy, 2016) aimed at decreasing the use of resources without income losses. This development stimulates companies to invest in additive construction technologies, also known as 3D printing or rapid prototyping, as appropriate procedural systems to reach costs and times reduction in works realisation (Lipson and Kurman, 2013).

In a broader framework, the automation machines used within the construction industry [Fig.1] are computer-aided, semi-automated, and automated equipment intended for the soil moving (handling diggers), for the shaping of construction components (installation, forming, and subtractive robots), and for the definition of customised volumes (additive construction systems). They have recently found an application within building site operations as a chance to update the standard building process (Bock and Thomas, 2016). In particular, the additive 3D printing technology provides the opportunity to manage the creation of complex shapes and volumes by depositing overlapping layers of proper printable new mixtures. It allows operating a large quantity of information coming from specific software and ensures the accurate measurability of the resources involved in the realisation and the forecasting of all implementation steps (Codarin, 2016).

Latest large-scale fabrication systems are mainly divided into cold extrusion and powder-bed deposition and both of them allow the simplification of realisation processes from the design phase to the digital model elaboration, to the output definition. Cold extrusion machines consist of an extruder calibrated to lay strata of a viscous blend that solidifies instantly. Powder-bed deposition technique, instead, provides a system of mechanical jets programmed to set down alternate layers of a base material and a

1 / The first digital revolution refers to economic, politic and social changes due to binary-language introduction. The second digital revolution, according to Neil Gershenfeld's (2012) definition, is related to the development of technology in matter.
2 / For further information see: http://cba.mit.edu/docs/papers/12.09.FA.pdf (accessed: 15/04/2017).

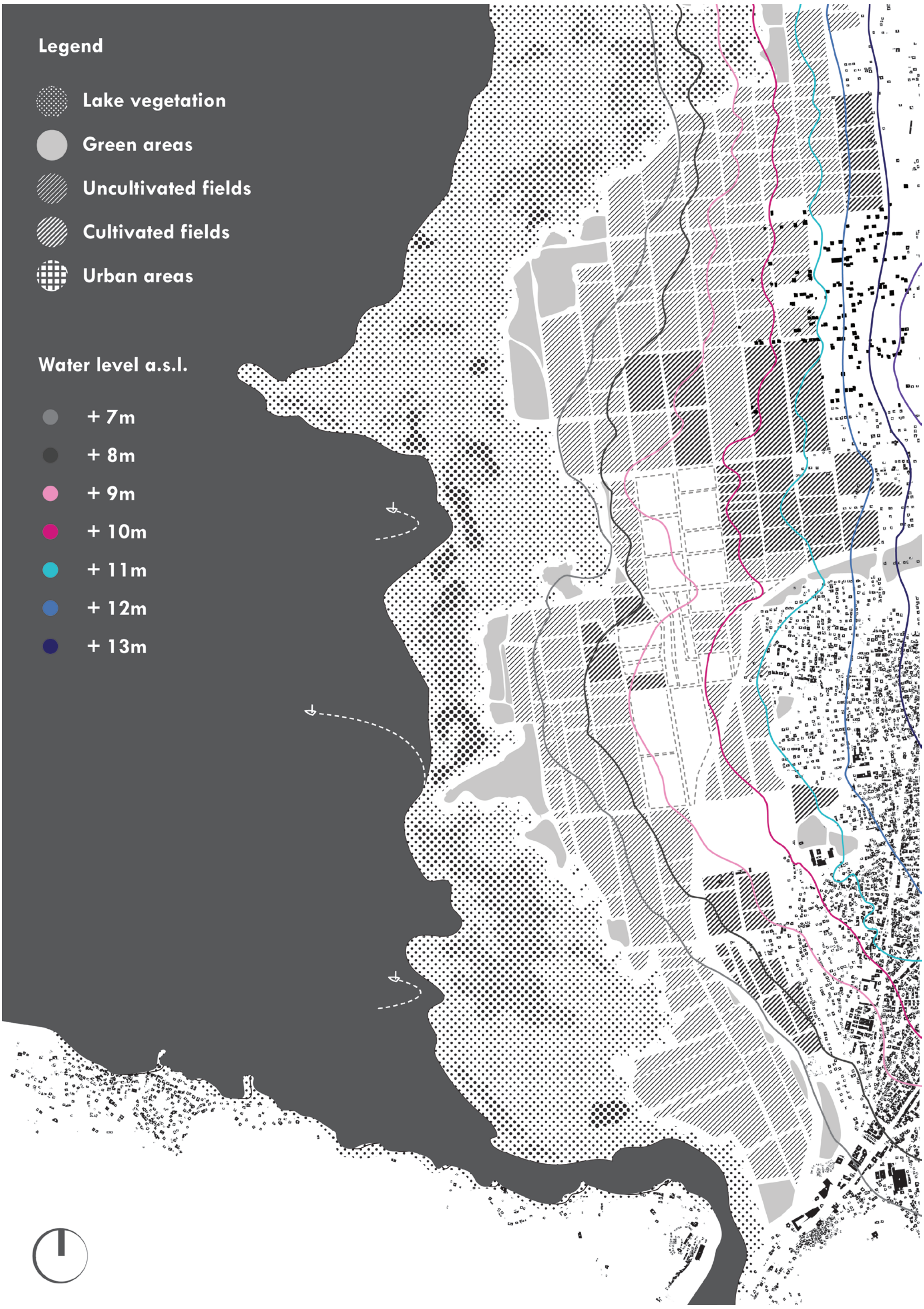

Fig2 / Masterplan of Shkoder's shoreline. The image shows the transition of landscape features from the surface of the lake, through the protected natural area, to the city edge. In the event of flooding, water level can rise from 4m above the sea level (normal situation) to 13m, causing damages both on the Natural Heritage and urban land
source / the author

binder [Fig.2]. These advanced 3D printing systems are able to process new materials that are environmental compatible and multi-scale adaptable (Beorkrem, 2013). For this reason, we can consider these technologies a potential not only for architectural realisations, but also for landscape renovation projects with the aim of defining innovative constructive scenarios. A possible application could be recovery measures for damaged natural frames as a consequence of impactful human activities.

Human imprint is responsible for growing stress on land and water with, consequentially, territorial degradation, since urbanisation, infrastructure connections, and constructions spreading are the principal reasons for the pressure of landscape quality. A specific attention should be pointed on wetlands, which are contexts that more than others require attentive analysis to prevent environmental issues.

Fig3 / 3D printer that works with powder-bed deposit. It allows the definition of free-form volumes in any direction. The printing resolution is variable according to the features of the machines source / photos of Dshape

In Europe, plurennial strategic programmes play a key role to encourage aquatic ecosystems protection, green networks realisation, energy consumption optimisation and sustainable tourism promotion. The programmatic agenda includes the EUSAIR (European Strategy for the Adriatic and Ionian Basin) for the monitoring of coastal areas in the EU Member States as well as non-EU Countries, in order to strengthen the quality of the whole geographical territory. The EUSAIR programme embraces several complex systems of the Balkan Peninsula, such as the watershed of Lake Shkoder and River Buna (counted in the Ramsar List of Wetlands of International Importance), which is strongly affected by unsustainable land-based activities on shoreline areas and aquatic ecosystems. It is considered a significant context to be taken as a case study. [Fig.3]

A complex environmental system: the case of Shkoder

The city of Shkoder is located in a valley that contains a wide variety of natural features, classified within the AKZM , such as the lake, the rivers and the coastal lagoon, the freshwater marshes, and the alluvial forests. Shkoder has a significant potential for future tourism development, which is not fully exploited for various reasons. Uncontrolled city sprawl, water pollution and vegetation impoverishment hamper the attraction of tourists. During the last years, several flooding events had ran over the city on a regular seasonal basis, causing significant damages on buildings and natural areas. Nevertheless, because of the watershed topography, floods represent a given condition that the landscape and the urban settlements have unavoidably to deal with. Shkoder's environment raises issues on land management, biodiversity protection, and public space organisation in protected areas. Its complexity represents an opportunity to transform local problems into potentials. Shkoder is delimited on the south by the river Kir, a tributary of the Drin that flows into the Buna. The latter derives from Shkoder's lake and flows in its delta in the Adriatic Sea. The intersection of the rivers is a critical node during rainy periods, as the outflow stream is not sufficient to face water income due to weather conditions. Indeed, according to UNW-AIS dataset , the level of the lake rises in January and November forcing the

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3 / The Ramsar Convention had the objective to develop and maintain an international network of wetlands that are important for the conservation of global biological diversity and for sustaining human life through the maintenance of their ecosystem components, processes and benefits/services. For further information see: http://www.ramsar.org/ (accessed: 10/04/2017). Albania joined the Ramsar Convention in 1995 and, in 2006, it has taken the opportunity to designate its third Ramsar Site, the watershed of Lake Shkoder and River Buna. Available at: https://rsis.ramsar.org/ris/1598 (accessed: 12/04/2017).

4 / National Agency of Protected Areas in Albania. It has the objective to protect natural areas from land misuse and promote soft tourism development. Available at: http://www.akzm.gov.al/index.php?option=com_k2&view=item&id=200:skadar-lake&Itemid=437&lang=us (accessed: 12/04/2017).

5 / Available at: http://www.ais.unwater.org/ais/aiscm/getprojectdoc.php?docid=1445 (accessed: 12/04/2017).

6 / At the following link http://reliefweb.int/sites/reliefweb.int/files/resources/5660FD9F6FBE2DD1C12577F2002CF10B-map.pdf (accessed: 12/04/2017) it is possible to find the map of the flooding events that occurred over the city of Shkoder in 2009 and 2010. The graphic shows the impact of a change in the local water level on the environmental system.

Fig4 / The 3D printed pedestrian bridge experimented in Madrid by Dshape and IAAC, through powder-bed deposit processing. It represents the first landscape component realised by the application of large-scale rapid prototyping.
source / photos of Dshape

water to run over coastal lands, suburb areas, and the city centre [Fig.4].
Local administrations have realised a gravel dike (a structural landscape intervention) to face the issue of flooding, as an attempt to contain the problem, even though it is not related to any wider-scale strategic planning. Indeed, this construction has caused a modification of the existing natural features: during floods, water is forced to flow under the soil where often stagnates, unbalancing the shoreline ecosystem assets. In addition, from a nature point of view, Shkoder's watershed is affected by water pollution (primarily determined by urban wastewater and illegal discharges) with long-term effects on flora (shortage of nutritive substance and sedimentation in water), fauna (scarcity of living organisms), and habitats (deterioration of the biodiversity). These effects involve also water flows that, during flooding events from the lake to the urban land, do not get slowed because of the absence of coastal vegetation, that should act as a shielding element.
On the basis of this environmental framework, it is possible to conceive new scenarios of landscape renovation interventions, as pilot projects for other similar contexts (Pazzi et al., 2015) including the enhancement of the overall environmental quality and the enrichment of the local ecosystem, by using 3D printing tools.

A proposal for a repeatable unitarian strategy of intervention

An approach is proposed that aims to provide an effective operative tool that goes from mapping the primary emergencies of the study areas, to design elaboration, up to realisation.

In the case of Shkoder, the aim is to find an effective methodology that can help systematize the renovation of the lakeside, starting from the recognition of the peculiarities of the context and their eventual level of damage. To achieve this result, we should set multi-dimensional and multi-targeted objectives (spanning from a simple landscape unit to larger territorial elements), to be organised in different phases.

3D printing technologies can generate a sustainable landscape renovation intervention (on site or in nearby production centres) through a procedure which is assumed to be repeatable in critical backgrounds comparable to those examined, according to the following expected results:
- redefinition of the coastal margin through 3D printed components (walking paths, observation platforms) and proposal of a low-cost qualitative design to strengthen its identity, based on the application of non-structural interventions and the use of compatible materials, with the objective to achieve a unitarian readability of the fragmented landscape pieces [Fig.5];
- reconnection of the shoreline with urban and suburban lands;
- physical and social integration between the city and its periphery, to encourage the local government to promote the realisation of renovated spaces suitable to be used by the community;

Fig5 / Sections of the 3D printed pedestrian bridge. The organic-shaped volume follows forms of nature with the aim of optimising the mechanical performances and the use of resources by recycling the raw material during manufacture
source / photos of Dshape

- promotion of an innovative landscape planning to attract nature tourism by developing activities based on ecosystems observation;
- enrichment of the biodiversity of the protected natural areas. 3D printed components (reefs or artificial margin) can represent an instrument to encourage the liveability of the underwater environment (once the lake surface overflows) and the reinforcement of vegetal settings, acting as a sedimentation collectors (after the water level returns to its normal configuration). Flora densification is, therefore, a key factor to restrain water flows during floods [Fig.6];
- definition of a resilient shoreline which is adaptable to the different seasonal configuration, due to water level changes, to limit irreversible environmental damages and economic losses.

In Shkoder's framework, the powder-bed deposition system, enables printing of organic-shaped blocks made of a sand-based material and binders. In this study, we consider it the most suitable system to generate landscape technological components for renovation processes.
Recent experiments have shown that 3D printed elements resist effectively atmospheric agents and water pressures, without losing material consistency or aesthetic quality. This aspect is fundamental to promote long-term intervention actions.

Realised experimentations analysis: limits and potentials

The 3D printing powder-bed deposition technique, which allows the printing of monolithic shapes in morphological continuity with the environment without geometric constraints, in 2008 led to the construction of Radiolaria, the first architectural full-scale prototype, designed by Dshape in collaboration with Shiro Studio. It was composed by a single three-dimensional block made of 5mm-layers, which represents a transition towards the use of free forms in architecture.

The experiment signified the possibility to initiate new construction scenarios by using a load-bearing stone-like material, composed of sand, metal oxides, and inorganic salt-based binders, which refers to the current European regulations about natural stones (porosity, compressive and flexural strength).
From this starting point, researchers -supported by promising market forecasting- focused on the possible adaptation of different 3D printing systems for large-scale realisations (based on production optimisation and

7 / There are a number of adaptation options that could be used for reducing the vulnerability of a coastal system. One way of classifying these adaptations is as structural and non structural interventions. Structural interventions attempt to change the physical conditions of the natural system. They seek to use engineering to make the natural environment more capable of withstanding extreme events. Non-structural approaches employ land-use controls, information dissemination and economic incentives to reduce or prevent disaster vulnerability.
8 / Prefabrication of assembly pieces can be addressed either moving the machines or their products. The subdivision of the design system into a finite number of transportable and storable parts raises new challenges in innovating the established key stages of the construction process.

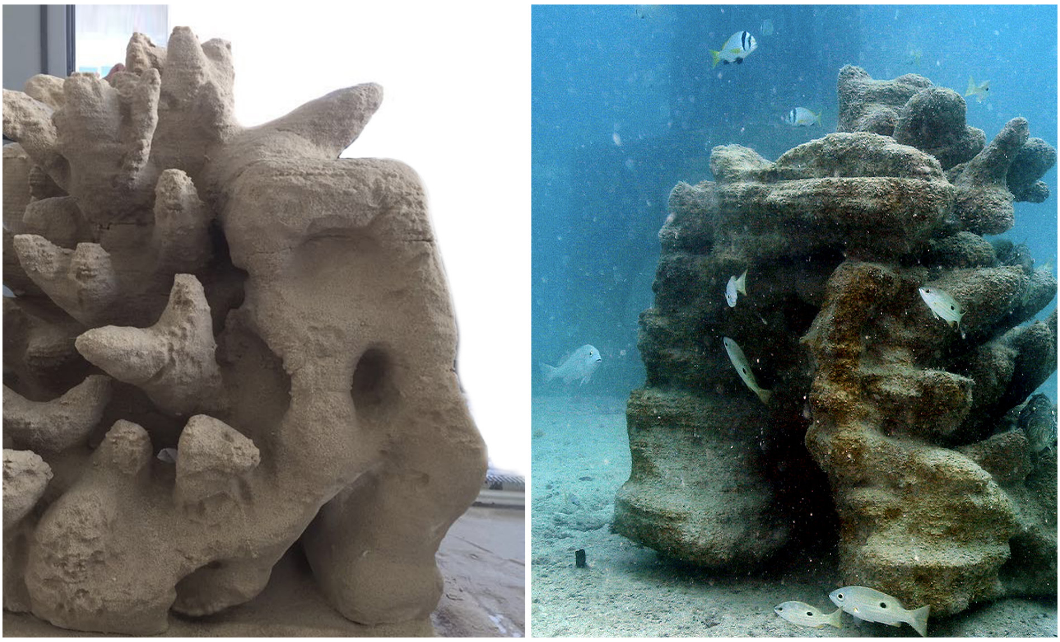

Fig6 / Reef prototype and its experimental positioning underwater. It represents a natural habitat for the aquatic ecosystem. The geometric layout is also effective to strengthen the morphology of the coastal margin
source / photo by Dshape

waste reduction) in order to find a new market segment between the artisan and the mass production (Sennett, 2008).
Several companies have therefore developed printing machines for building construction, to perform pioneering experimentations encouraged by the fact that beyond the initial investment to buy the machine, any tests are feasible only considering the price of the material, which is the major cost component (Rindfleisch, 2017).

Recent large-scale 3D printed realisations have been carried out (Stevens and Ralph, 2015) by using concrete (multi-level building designed by Winsun Company), clay (residential unit by Wasproject) or sand (emergency residential module by Dshape).

However, in order to meet national or local regulations requirements, new constructions need the hybridisation with traditional techniques for structural reinforcements, as printable materials are not yet mature to bear considerable flexural and tensile stresses. In fact, the search for 3D printable mixtures is still under way.

A representative case study for landscape interventions, developed by Dshape and Boskalis Companies , concerns the 3D printing of underwater free-form reefs, aimed at restoring deteriorated coastal habitats [Fig.7]. These objects, prototyped as full blocks (not assembled elements), are characterised by a complex geometry suitable to create an artificial environmental system for aquatic living organisms. The realisation of monolithic volumes, in fact, avoids the installation of incompatibles elements with the surrounding natural background (Teizer, 2016). For each experimentation in different contexts (the reef has been positioned experimentally in seabed and coastal underwater environment of Monaco Principality, Bahrain, and Rotterdam), the reefs have been produced by ensuring durability over time and hydrostatic forces resistance. Compared to the usual systems used to enhance underwater habitats (perforated volumes made of concrete), 3D printed reefs can be realised with a more complex geometry, that means more similar to the real habitats, with minimal material waste.
These construction procedures respond to the principles of the biomimetic design, which is a technological application of the biological key features of nature (by identifying those principles that enable resilience, material adaptability, and load bearing efficiency) within the implementation of complex shaped objects (Reichert et al, 2014).

The powder-bed deposition leads to the creation of organic structures, which can be integrated both on the land or water bottom, by simulating the formation of sedimentary rocks in the underwater environment. At the same time, the fabrication process allows defining monolithic massive elements (instead of plural units), characterised by mechanical properties that are attributable to natural-origin models.

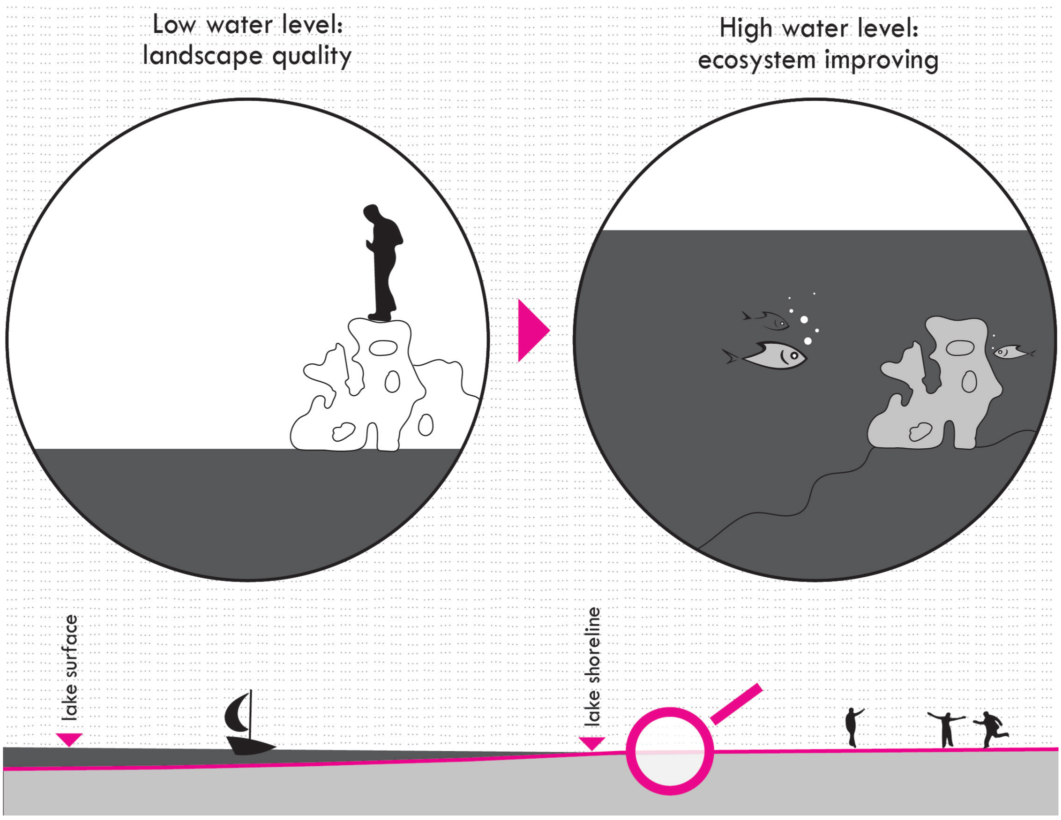

Fig7 / 3D printed organic shaped reefs as a landscape project proposal for Shkoder's Lake shoreline. The intervention is intended to be resilient to the changes of water level –according to the biomimetic design principles- and effective to provide both territorial quality and biodiversity enhancement source / the author

A next developing step may provide the possibility of using case-by-case local sands as the principal inert of the printable mixture, matching with the natural context, which should be tested to ensure the proper mechanical resistance.

For instance, chemical-physical composition of Shkoder's soil could influence the amount of binder needed for the base material for powder-bed deposition and, as a consequence, the precision and the geometric layout of the resulting prototype.

Moreover, the dimensional scale of each 3D printed component should follow specific studies on the dynamics of the surrounding natural context, such as the speed of water flows in case of underwater positioning or the resistance to the local atmospheric variable conditions, when the printed components are exposed.

Conclusions

3D printing processes are considered as a potential innovative approach to face Shkoder's emergencies in the framework of a compatible landscape planning within a natural, protected area. This, in compliance with European regulation that are being developed on the theme of the use of new automated systems for building constructions and landscape components. It is possible to prefigure the realisation of a 3D printed soft-infrastructure (such as the first 3D printed pedestrian bridge realised in Madrid by Dshape and the IAAC) that can link the most valuable units of the context [Fig.8]. In this way we can manage to connect the non-functional spaces between the city and its surrounding settlements. The objective is to define a non-interrupted territorial system as a potential for the foreign and local tourism, addressed along the designed paths to focus on naturalistic activities. Moreover, in order to revitalise Shkoder's

9 / For further information see: https://3dprinting.com/news/winsun-uses-waste-3d-print-houses-4800-dollars/ (accessed: 02/07/2017).
10 / For further information see: http://www.wasproject.it/w/en/3d-printed-houses-for-a-renewed-balance-between-environment-and-technology/ (accessed: 02/07/2017).
11 / For further information see: http://design.repubblica.it/2010/11/22/la-casa-tutta-di-un-pezzo/ (accessed: 02/07/2017).
12 / Available at: https://magazine.boskalis.com/issue03/3d-printed-reefs (accessed: 14/04/2017).
13 / The project was presented at the 13th International Coral Reef Symposium. For further information see: https://www.researchgate.net/publication/311615466_3D_printed_reefs_as_an_enrichment_for_natural_habitats (accessed: 15/04/2017).
14 / The present case study represented a successful experimentation of the large-scale 3D printing in urban spaces, so that this technology will be used to realise the street furniture for Dubai 2020 masterplan. For further information see: https://d-shape.com/ (accessed: 14/04/2017) and https://iaac.net/ (accessed: 12/04/2017).

waterfront biodiversity, the positioning of articulated reefs, appropriately sized based on simulation of incident forces in the lake bottom, can result in a qualitative factor, able to adapt to different landscape configurations, according to the requirement of landscape adaptability. During floods, the stone-like structures belong to the underwater environment, while in non-emergency conditions they act as emerged sedimentation absorbers, to encourage coastal habitats enrichment. Based on available technologies and open issues, the proposed innovative intervention approach can represent a key point for future insights.

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Fig8 / Project proposal for the shoreline of Shkoder's Lake, composed of 3D printed landscape components made of a stone-like material mixed with local sands and realised through powder-bed deposition processing. The walking paths and the organic-shape reefs contribute to create a soft biomimetic infrastructure, compatible with the character of the natural protected area
source / the author

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