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Data-Driven Research on Ecological Prototypes for Green Architecture: Enabling Urban Intensification and Restoration through Agricultural Hybrids

Defne Sunguroğlu Hensel

Editorial Summary: In »Data-Driven Research on Ecological Prototypes for Green Architecture« Defne Sunguroğlu Hensel introduces a design research attempt to the field of environment design, landscape, architecture, and green technologies in the context of urbanization, questioning the interrelation of architectural buildings and ecological, agricultural, and natural free space. This research proposes their inclusive interplay, aiming to dissolve the notion of construction as a driving force of land degradation and instead emphasizing its potential to facilitate green infrastructures in the realm of the built environment. Green constructions are described as a reasonable interlocking of architectural basic structures and their agricultural or horticultural use. She analyzes historically proven examples, underlining their contemporary potentials for adaptation and transition. [Katharina Voigt]

Keywords: Urbanization; Environment; Green Construction; Data-Driven Design; Decision; Ecological Prototypes; Urban Agriculture; Urban Restoration.

Introduction

Environmental deterioration caused by rapid urbanization and climate change constitutes a major challenge for architecture in the 21st century. Construction is causing significant loss of agricultural and forest landscapes, degradation of ecosystems, depletion of natural resources, and decline in biodiversity and carbon stock as well as human-wildlife conflict (a trigger for pandemics such as Covid-19) (Salehi/Woodbridge/Arikan 2017; Groffman, et al. 2017; McDonald, et al. 2020; Güneralp, et al. 2013; World Economic Forum 2018). Humans depend on the services that nature provides for their health and well-being (Millennium Ecosystem Assessment, 2005). Land use and cover change and transformation through urban expansion and densification threatens the delivery of essential ecosystem services, i.e. food production

Corresponding author: Defne Sunguroğlu Hensel (Vienna University of Technology and Technical University of Munich); defnesunguroglu@lamolab.net; https://orcid.org/0000-0003-2968-6432

and local climate regulation, as well as various other benefits derived from nature and human-nature relationship. Urban land take in Europe continues to exceed the target limit of 61,100 hectares/year to achieve »No Net Land Take« goal by 2050 (Science for Environment Policy, 2016). While construction and human intervention is often considered a major driver of environmental degradation, they are not necessarily always harmful. In fact, they can be vital for the protection, support, and enhancement of ecosystems and the delivery of services, as seen in historical agricultural systems for example (Pasta et al. 2017; La Mantia/Carimi/Di Lorenzo/Pasta 2011). Moreover, construction can even play a key role in sustainable intensification of urban agriculture and restoration to enhance ecosystems and service delivery in the urban environment.

Urban agriculture and land restoration can contribute to mitigating the negative environmental impact of rapid urbanization, and if integrated in architectural design and planning decisions even help reconcile urbanization with nature. In this context, urban agriculture and restoration is considered as a combined strategy to reverse past degradation that result from urbanization while avoiding and reducing new degradation in the continuous process of adapting and transforming the environment to protect and meet not only humans and their needs but also nature and the needs of other species. Some of these efforts are currently taking place at the landscape scale involving forest landscape restoration, restoration ecology, and ecological engineering. These include forestation, conservation, and sustainable management practices, as well as integrated land use planning, which goes beyond the classic agricultural intensification and land-sparing strategies. Other strategies, applicable at architectural and planning scales, include land recycling by building on brownfields, densification by filling gaps in the urban fabric, compensation for land taken by returning abandoned building land to agricultural, forest, or other types of semi-natural land cover, and minimizing buildings' negative environmental impact. Biodiversity, climate change, and human well-being challenges are drawing increasing attention to urban green infrastructure (UGI) and green architecture in terms of their potential to offer sites for incorporating plants in buildings and cities, i.e. vertical forests, green facades and roofs, or urban forests, urban agriculture, and green corridors (Rinaldi, Bianca; Tan, Puay Yok 2019).

Minimizing the environmental impact of land and resource consumption, construction and buildings through resource efficiency and boosting nature and agriculture in cities for climate change adaptation and mitigation, human well-being and biodiversity are some of the primary motivations for contemporary green construction (GC). This has already led to new green buildings, i.e. vertical forests like the Bosco Verticale in Milan by Stefano Boeri or the Biodiversity Tower M6B2 in Paris by Eduard Francois. There exists also a growing interest in ways in which the combination of green roofs and facades can act as green conservation tools, enhancing biodiversity, as well as more broadly, the integration of biotic and abiotic components of green buildings (Dover 2015). Buildings can make provisions for establishing vegetation on sites which have been lost to or cleared for construction. However, they are typically not designed for enhancing a habitat to increase its suitability for some target species and agricultural practices selected for their particular multiple ecological and service benefits. The latter is a substantially different approach compared with conventional approaches to green architecture that we are accustomed to see in cities. As a result, construction while being a mechanism for adapting the environment to suit human needs, is hardly conceived as a tool for intensification, by making it possible to achieve higher-level cultivation (both quantitatively and qualitatively) without dependency on unsustainable and resource intensive methods, and restoration, by introducing species and practices that are not only beneficial for humans but also local ecosystems. Therefore, while some buildings manage to integrate elements of green infrastructure, they can hardly be considered a means of ecological restoration and intensification. Achieving this goal requires a systematic and integrated design and planning approach, and coordinated, systemic and accumulative interventions at the architectural scale. Currently we lack the evidence base and design methods to adequately bring data and green construction intelligence into decision making processes.

In this context GC systems are characterized in terms of their capacity for agricultural intensification and ecological restoration, which determine the multifunctionality of green construction. The first attempt to mapping these systems show that at one extreme, GC typologies tend towards fully-enclosed systems of food production that are decoupled from their natural environment with detrimental environmental impact due to high input and no ecological significance. At the other extreme, they are structures and practices that enable extensive horticulture with either high or low external input. These types often provide ecosystem functions to a lesser extent. Historical agricultural constructions enable sustainable cultivation in challenging environments and provide solutions that work with local climatic and ecological conditions, available materials and renewable resources, and do not depend on external input, i.e. energy. These range from provisions for single plants, to extensive farming at the landscape scale, and urban farming with ecological value. Ecological prototypes, a notion introduced to refer to systems for architectural adaptation to facilitate agricultural intensification and ecological restoration simultaneously stand for a new type of GC. These novel systems are hybrid adaptive systems of design, construction, and practices that link architecture, horticulture and agriculture, landscape, and ecology. This is the area where research is most urgently needed. These novel systems are being investigated for their potential to enable high-value plants and farming practices in urban environments, which are otherwise challenging and unsuitable conditions for their cultivation. Special attention is given to developing systems with better capacity to balance and reconcile intensification, restoration and sustainability objectives in delivering ecosystem support and improved services in the built environment.

Data-Driven Research and Development of Ecological Prototypes

One of the objectives of ecological prototypes research is to learn from historical land systems that have evolved over generations. Solutions from the past can facilitate not only design innovation for next generation GC, but also help identifying questions that need to be asked to design better GCs for the changing needs of our time. These traditional agricultural land uses draw on natural and locally available resources and ecosystem services in an economic way to facilitate the cultivation of valuable crops in challenging environmental conditions. They also play a key role in the delivery of services like micro-climate regulation, which benefits plants and cultivation. In these examples, crop cultivation is facilitated through a combination of biotic means, i.e. introduction of a new species, plant manipulation (horticultural practices), and abiotic means, i.e. the dry-stone wall constructions that transform a slope into terraced landscapes and modify environmental gradients through added thermal mass to facilitate high quality vine production at high altitudes. The least intrusive systems include forest farming and forest gardening, as well as ancient methods such as *vite maritata* that utilizes trees as scaffolds for growing vine (Buono/Vallariello 2002). Systems with a slightly higher degree of intervention are characterized by modifications of the terrain. Examples are the funnel-shaped soil indentations for growing individual vine plants on the Canary island of Lanzarote, the terracing of slopes that can be found in many regions of the world, or structures that support plants in various ways. The latter include the use of scaffold-like structures for growing vine, lemon, or hop and linear constructions such as dry-stone or masonry walls, or Devon hedges made from earth banks faced with stone or turf with native trees and shrubs growing on it. More elaborate systems are dry-stone walls in conjunction with terraced landscapes, or as perimeter structures for walled gardens, such as the ones on the Italian island of Pantelleria (Lommatzsch/Brignone 2007). Dry-stone or masonry walls can be individual structures, such as the serpentine walls in England, or extensive systems spread over large areas, such as the peach gardens in Montreuil near Paris, France, that utilize so-called fruit walls. These types can either be open field systems or provide an enclosure such as the talut walls. Fully enclosed greenhouses originally evolved from the fruit wall with leaning glass surfaces, i.e. talut walls, later came to encompass three quarter span greenhouses, conservatories, orangeries, hothouses, and eventually contemporary industrial greenhouses to intensify and sustain production throughout the year. Significant progress in this regard emerged through the works of Louden, Paxton, and others (Hix 1974). Greenhouses can be further distinguished by the degree to which mechanical and electrical means are used to produce a controlled artificial interior climate.

Initial sets of data on historical agricultural/horticultural systems are currently being collected. This data comes from individual field surveys, literature sources, and various methods of analysis to be structured and integrated in a decision support system for research and development. This historically-derived information will include – but is not limited to – the following cases: (1) linear structures such as the dry-stone walls and terraced landscapes of Lamole in Italy, fruit walls of Thomery in France, and Serpentine walls in England; (2) perimeter structures such as the singular walled gardens of Pantelleria in Italy, and aggregated walled gardens such as the peach orchards of Montreuil sous Bois in France, and the volcanic vineyard landscapes of Lanzarote in Italy; (3) enclosed structures such as the lean-to and vaulted hot houses and early green houses; (4) transformable structures such as the lemon houses (limonaie) of Lake Garda; and (5) practices without structures such as Vite Maritata. Systematic and comparative analysis of diverse types of historical land systems is crucial for understanding the functional attributes that result in multiple benefits derived from these systems, including ecosystem services. Comparability of the performance of existing GC solutions from a multifunctionality perspective enables integrating historical knowledge in the implementation and adaptation of strategies and solutions to foster long-term persistence and resilience, and to changing requirements and conditions, which necessitate design innovation in order to be able to address complex GC challenges of our time.

Discussion

Historical data constitutes only a part of the necessary datasets for research, experimentation and development of novel GC systems. Another comes from research-by-design experiments which involves prototypical tests and full-scale constructions carried out as laboratory and field experiments. These design and construction experiments facilitate the generation of new data while at the same time using insights and information derived from historical data for experimentation and validation of theoretical results. Hence, a line of research on Ecological Prototypes focuses on earth-based materials and structures, which has a long history in the evolution of GC system typologies. A strong motivation for massive construction shaped by local materials (i.e. stone, soil, brick) was in particular to combine the advantages of structural and thermal mass. Therefore, these structures were often massive. In other contexts, heavy construction may be associated with significant trade-offs due to size and space occupied, material intensity and ground impact for which lightweight construction may be a better alternative.

The crinkle crankle or serpentine wall is an example for a historical technological innovation that shows one of the ways by which this trade-off was addressed in GC design. The serpentine is an undulating masonry wall system that is often only one brick deep, which is incorporated in walled gardens surrounding a house with the main purpose of training fruit trees across the sun exposed surface. It is a light-weight structural solution that provides stability without any additional supporting elements like the buttresses. Shape is a critical parameter as it provides stability while increasing the surface area of the wall. The change from flat to an undulating wall helps to generate more space for training fruit plants, optimize solar exposure and thermal energy storage, and protect the plants from cold winds.

Many architectural examples make use of the undulating wall principle, as for example seen in numerous projects of Eladio Dieste. However, these are rarely designed also to provide for the specific needs of plants and agriculture/horticulture. This strategy is being investigated in research focused on the development of a GC system called Nested Catenaries.

The first developmental phase of this research (Sunguroglu Hensel/Bover 2013), focused on questions of integrating spatial and structural design of an unreinforced masonry construction, a thin vaulted shell structure that can achieve large spans and resist dynamic loads. The next phase of development focuses on environmental questions including the modification of microclimate and environmental gradients to suit particular plant and agricultural practice needs. Nested Catenaries is one of the systems being developed in the context of ecological prototypes research.

Conclusion

This research introduces the concept of ecological prototypes, a novel type of GC system, and some aspects of the data-driven experimental and developmental design research framework. Ecological prototypes are described as the new generation GC and as integrated and adaptive design and construction systems. These systems link architecture, agriculture/horticulture, landscape and ecology to facilitate the protection, support, and enhancement of ecosystems and services in urban environments. The development of ecological prototypes for learning, adaptation, and application in environments with similar conditions and requirements necessitates bringing GC knowledge into data-driven design. This chapter focused on the historical case study research and the role of this dataset in experimental design research. It is important to note that the historical data is only a part of and not the only data-set that is being acquired, analyzed and structured for the purpose of ecological prototypes research. EPOC decision support system is currently being developed to model, manage, integrate, interrogate, and capture research relevant information through linking various computational methods and processes, including an expert database, where also the historical data is stored and collected (Sunguroglu Hensel 2020). Based on this approach, novel ecological prototypes can evolve with the aim to facilitate GC systems for architectural and context-specific adaptation, and sustainable construction that can enable ecological intensification of urban agriculture and restoration for enhanced ecosystem support and delivery of urban services.

References

Buono, Raffaele/Vallariello, Gioacchino (2002): »La vite maritata in Campania«, in: *Delpinoa* (44), 53–63.

Dover, John W. (2015): *Green Infrastructure: Incorporating Plants and Enhancing Biodiversity in Buildings and Urban Environments*. London/New York: Routledge.

Groffman, Peter M./Avolio, Meghan/Cavender-Bares, Jeannine/Bettez, Neil D./Grove, Morgan J./Hall, Sharon J. et al. (2017): »Ecological Homogenization of Residential Macrosystems«, in: *Nature Ecology & Evolution* 1(7), 1–3.

Güneralp, Burak/McDonald, Robert I./Fragkias, Michail/ Goodness, Julie, Marcotullio, Peter J./Seto, Karen C. (2013): »Urbanization Forecast, Effects on Land Use, Biodiversity, and Ecosystem Services, in: Thomas Elmqvist/Michail Fragkias/Julie Goodness/Burak Güneralp/Peter J. Marcotullio/Robert I. McDonald/Susan Parnell/Maria Schewenius/Marte Sendstad/Karen C. Seto/Cathy Wilkinson (eds.), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, Dordrecht/Heidelberg/New York/London: Springer Open, 437–453.

Hix, John (1996[1974]): The Glass House, London: Phaidon.

La Mantia, Tommaso/Carimi, Francesco/Di Lorenzo, Rosario/Pasta, Salvatore (2011): »The Agricultural Heritage of Lampedusa (Pelagie Archipelago, South Italy) and Its Key Role for Cultivar and Wildlife Conservation«, in: *Italian Journal of Agronomy* 6(2), 106–110.

Lommatzsch, Ines/Brignone, Francesco (2007): »Die Jardini von Pantelleria«, in: *Orangerien in Europa. Von fürstlichem Vermögen und gärtnerischer Kunst, ICOMOS – Hefte des Deutschen Nationalkomitees* (43), 86–90.

McDonald, Robert I./Mansur, Andressa V./Ascensão, Fernando/Colbert, M'lisa/Crossman, Katie/Elmqvist, Thomas, et al. (2020): »Research Gaps in Knowledge of the Impact of Urban Growth on Biodiversity«, in: *Nature Sustainability* 3, 16–24.

Millennium Ecosystem Assessment (2005): *Ecosystems and Human Well-Being: Synthesis*, Washington, DC.: Island Press.

Pasta, Salvatore Claudio/Ardenghi, Nicola M. G./Badalamenti, Emilio /La Mantia, Tommaso/Console, Salvatore Livreri/Parolo, Gilberto (2017): »The Alien Vascular Flora of Linosa (Pelagie Islands, Strait of Sicily): Update and Management Proposals«, in: *Willdenowia* 47(2), 135–144.

Rinaldi, Bianca/Tan, Puay Yok, eds. (2019): *Urban Landscapes in High-Density Cities. Parks, Streetscapes, Ecosystems*. Basel: Birkhäuser.

Salehi, Pourya/Woodbridge, Michael/Arikan, Yunus (2017): *Land degradation and cities. ICLEI Briefing Sheet* (3), 1–4.

Science for Environment Policy (2016): *No Net Land Take by 2050? Future Brief* 14, Bristol: Science Communication Unit.

Sunguroglu Hensel, Defne (2020): Ecological Prototypes: »Initiating Design Innovation in Green Construction«, in: *Sustainability, MDPI, Open Access Journal*, vol. 12(14), 1–17.

Sunguroglu Hensel, Defne/Bover, Guillem Baraut (2013): »Nested Catenaries«, in: *IASS Journal of the International Association for Shell and Spatial Structures*, 39–55.

World Economic Forum (2018): *Shaping the Future of Construction: Future Scenarios and Implications for the Industry*. Cologny/Geneva: World Economic Forum.