World Academy of Science, Engineering and Technology
International Journal of Urban and Civil Engineering
Vol:17, No:12, 2023

Achieving Implementable Nature-Based Solutions While Reshaping Architectural Education: A Case Study of URBiNAT and BUILD Solutions

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***Abstract*—**Nature has often been something humans have fought against. However, with the changing climate and urban challenges such as air pollution and food shortages, to name but a few, it has never been more crucial to work with nature to find solutions that can help us to adapt to the current planetary situation and mitigate the challenges that we will continue to face in the future. Nature-based solutions (NBS) have been gaining ground as one strategy that can help to create more sustainable solutions for our planet and simultaneously, provide several ecosystem services. As designers, there are a lot of insights that can be extracted and gained from nature. However, nature is a complex and sometimes difficult to predict system and its implementation in cities requires a multidisciplinary knowledge. To keep up with the solutions and prepare the future generations of architects and designers with the skills to be able to implement NBS, educational systems also have to adapt with the times. Architecture is no longer solely about drawing buildings with beautiful forms. It is no longer discipline bound. With the input from different disciplines, the implementation of NBS can be significantly more successful. Transdisciplinary strategies can encourage architects and designers to think beyond their discipline, and ensure the success and realization of the NBS. The paper will demonstrate how transdisciplinary teaching methodologies, including also taking part in participatory processes with experts intended as gathering local knowledge, can be implemented with architectural master students to achieve implementable NBS. Through two projects co-funded by the European Union, strategies such as participatory co-design and transdisciplinary start-ups were implemented into seminars that focused on the development of NBS with a transdisciplinary approach. Within the "Design with Living Systems" seminar, students took part in participatory co-design strategies with experts to design solutions that will be implemented in Porto as part of a healthy corridor, and that respond to the needs of the users and site. On the other hand, within the "Design for Living Systems" seminar, the transdisciplinary start-up approach created start-ups with students of architecture, business and biology focusing on identifying a problem and designing a NBS as a product. Both seminars proved to be successful in achieving implementable NBS through strategies of transdisciplinary education and gave the students the skill sets to be able to work with nature in their future careers.

***Keywords*—**Architectural higher education, digital fabrication, nature-based solutions, transdisciplinary approaches

I. Introduction

As nature evolves, so must the way in which architecture is taught to keep up with the challenges the planet is facing and provide students with the latest knowledge, tools and skills. The field of architecture is constantly expanding and must begin to consider the importance of a transdisciplinary approach through interdisciplinary and participatory education methodologies. These methodologies can provide new ways of solving problems and new perspectives that may have been missed from a mono-disciplinary approach [1]. Historically, education encouraged specialization, focusing on your discipline; however, today there is an ever-growing emphasis on relational knowledge [2]. An architect does not have in-depth knowledge of what plants would be suited to a particular environment, but a botanist could share with them this knowledge. Similarly, the architect does not know every place, while a local person knows in depth a place and its needs, and can explain what is required to increase the standard of living there.

Many concepts such as Urban Regeneration and Smart City have already been changing the way in which architects and urban planners have approached the design of cities, integrating aspects from fields historically not associated with architecture. Similarly, NBS have the opportunity to address the ever-pressing urban challenges being faced and integrate knowledge from different disciplines [3]. NBS 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" [4]. NBS create holistic solutions and pave the way for integrating transdisciplinary education methodologies through participatory strategies and interdisciplinary courses. The world's understanding of NBS is constantly growing and evolving as new projects emerge that expand and build upon the original definition of an NBS. Therefore, it is fundamental that in the design of NBS, multiple disciplines and stakeholders work together sharing their knowledge to create economic, social and environmental benefits.

At the Institute for Advanced Architecture of Catalonia (IAAC), the approach to designing NBS has been explored using transdisciplinary methodology. In the framework of the Horizon 2020 project URBiNAT [5], a transdisciplinary approach has been used for a seminar in which IAAC's students have to develop NBS to be located in a new healthy corridor in Porto, co-designed in collaboration with experts from urbanism,

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social science, politics, economics and local people. In fact, URBiNAT is a project focusing on urban regeneration in under-served neighborhoods of 3 cities, Porto, Nantes and Sofia, achieved through participatory processes. Through the combination of various types of NBS, the project seeks to create new healthy corridors that not only benefit nature, but also create a social impact by improving the wellbeing of residents. Healthy corridors are a term defined by URBiNAT as "a public space in the form of a pathway that connects and links neighborhoods, integrating not only NBSs but also human-centered ones, having an effect on the environment as well as on people's health and wellbeing" [6]. Through participatory processes and the input from different experts, the IAAC students designed part of the new healthy corridors with botanists and local people, resulting in NBS that meet their needs.

Another transdisciplinary approach has been tested with BUILD Solutions, an ERASMUS+ project co-funded by the European Union [7]. During this program NBS were designed by students from architecture, biology and business backgrounds in the form of a product that could pave the way for a start-up. Transdisciplinary research follows the structure of identifying the problem, analyzing it, and finally bringing the idea to life [8]. Through the BUILD Solutions project students directly worked in interdisciplinary teams following the structure above.

While both projects used different transdisciplinary methodologies with the students, they both resulted in implementable NBS. The following paper sections showcase the results of integrating transdisciplinary education including participatory methodologies with Master in Advanced Architecture students, in order to design and build functioning NBS.

II. NBS for Healthy Corridors

Participatory design has been gaining ground as a method to engage people of all ages in a co-design process. Using both digital and physical tools architects, urban planners, municipalities, to name but a few, are able to engage with users and inhabitants of spaces to understand both their needs and wants [9]. Rather than a top-down approach where someone is telling inhabitants what they need, now all stakeholders can have a say in the future of their city. Through URBiNAT, IAAC has been exploring how participatory design and NBS can be integrated as part of an academic Master program. The goal: to give students the tools and real-life experience to be able to implement NBSs in their future careers as well as integrate knowledge from experts in different fields and local people.

URBiNAT Porto provided the challenge of designing NBSs for 6 schools which are part of the healthy corridor, each with their own sets of needs and restrictions, but also opportunities. Not only does IAAC have to design and build these solutions, but the solutions had to be co-designed through participatory strategies with the teachers and children, aged 8-12, of the schools in Porto. For the master students of IAAC, a two-term seminar was designed (6 months long consisting of 40 hours of teaching) to teach them how to design with and for nature, and to give the students an opportunity to participate in a participatory design process and see their project implemented. The NBS had to provide cultivation areas for plants and encourage urban biodiversity providing a new educational tool for the teachers of Porto.

The overall structure of the seminar was designed in two phases with input from the schools in Porto at key phases of the design process. The first phase included a preliminary workshop with teachers and students in Porto, where the kid's made proposals for their cultivation areas through drawings and models.

Fig. 1 Proposals from Porto kids

With this in their hands, IAAC students within this first phase focused on research, including understanding what a NBS is, receiving classes about botanics, identifying the flora and fauna native or thriving in Porto, their needs and living conditions, and finally designing structural systems interpreting the inputs received by the kids and textures inspired by the ceramic tiles of Porto. The seminar consisted of presentations, as well as review sessions to go through and evaluate their proposals. Once the IAAC students had their first proposals of the structural system and textures, the designs were shared with the children of Porto for them to rate, comment, and associate and compare the drawings received with their original proposals through a series of workshops.

Fig. 2 Porto kids evaluating and rating IAAC students proposals

Fig. 3 Association between IAAC students' proposals and kids' proposals

Using the feedback from Porto, the IAAC students had to merge their structural systems and textures to design a prototype of their NBS. It was clear that the NBS the children reacted to most positively were the more playful solutions. The seminar resulted in three strong NBS to be implemented in 2023 in Porto that are outlined in the following paragraphs.

The first solution, a green wall, capitalized on the wet climate of Porto and the additive manufacturing technique of robotic 3D printing. During the seminar the students worked to develop the strategies for the design as seen in Fig. 4, and with the help of experts transformed their idea into a functional green wall. Fig. 5 shows the ceramic green wall being exhibited at the Smart City Expo in Barcelona, before being implemented in two schools in Porto. The solution consists of a set of ceramic, robotically 3D printed pots and tiles which will house insects, birds and plants as per the request of the kids. There are five ceramic typologies forming the wall as seen in Fig. 6, which reflect the needs of species of flora and fauna. The first typology is an insect hotel which is fully enclosed, filled with straw and sticks, and has a series of holes varying in size to encourage insects to seek refuge. The bird house has been designed based on traditional bird houses and provides a shelter for birds to roost or nest. In addition, there are the bird baths where water will be collected in basins. The remaining tiles and plant pots are divided into two groups with two different textures applied. The more exaggerated texture is to encourage moss growth, whereas the smaller texture was applied to continue the visual identity and navigate the flow of water. The children of Porto were drawn to the more exaggerated textures, hence the decision to mix the two textures, responding to the wishes of the children and the needs of the moss.

The texture integrated as part of the pots and tiles was specifically designed to capture sediment, water and spores to encourage moss growth on the tiles. This design was reviewed and tested with botanists in Barcelona, who provided invaluable information regarding the behavior of moss. The pockets would allow for spontaneous growth to occur as the shading and pools of moisture would provide the perfect habitat for moss, commonly found in Porto. Leaving the ceramic unglazed keeps the texture of the ceramic rough and allows the microbiota to easily attach itself. While parts of the ceramic wall are dictated by humans, other aspects are left to nature. The ceramic elements were carefully designed so that the elements would sit side by side and allow for water to pass from one pot to another. Integrating a self-watering system was a key input from the teachers, who wanted to minimize their maintenance tasks.

Working with ceramic poses challenges such as shrinkage, and therefore, several tests had to be conducted to allow fine tuning of the details with experts in the field. Using a robot to 3D print the elements, minimizes waste material and provides an infinite amount of designs.

Fig. 4 Textures developed by the students to encourage moss growth

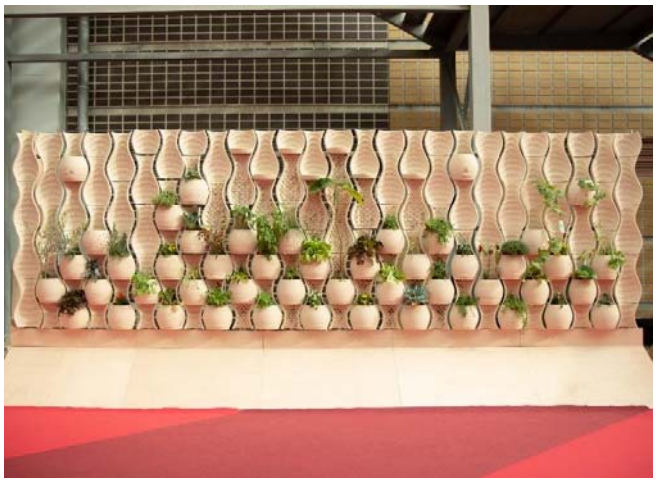

Fig. 5 Ceramic 3D printed green wall at the Smart City Expo

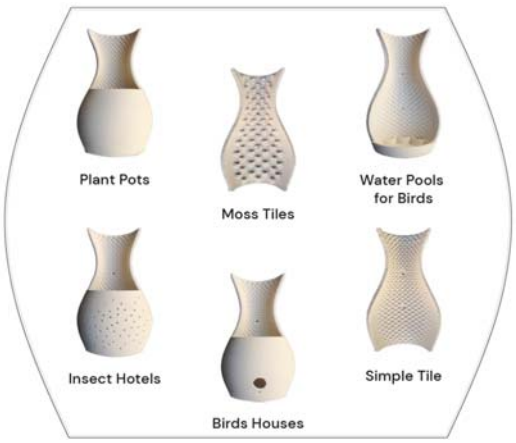

Fig. 6 Ceramic 3D printed pot typologies

Furthermore, the wall provides numerous ecosystem services for both the biodiversity and the humans that will interact with it. Through the co-design process and maintenance of the wall, it could be said that there are social services being achieved as it is encouraging social interaction. The wall provides habitats for insects and birds as well as providing different types of fruits and vegetables. The plants will also contribute to air filtration and pollination. These ecosystem services can be seen across the following NBS as well as per the requests of the teachers and children of Porto.

The second NBS is a timber CNC milled green wall as seen in Fig. 7 – the initial prototype. The children of Porto responded positively when the structure was playful and worked with curves. Therefore, the IAAC students used parametric software to respond, designing a wavy structure that houses plants, butterflies and has interactive elements. Using subtractive manufacturing, the students were able to achieve a series of layers that, once stacked, created pockets large enough to house herbs and flowers. The interactive nodes allow the children to learn from the wall as they observe the life cycles that are taking place inside, specifically encouraging butterflies. Working with wood creates a beautiful finish, but simultaneously several challenges as moisture and wood do not go hand in hand. To protect the wood, it will be coated to prolong its life and enhance the visual beauty of the wood.

Fig. 7 Green wall prototype developed by the students

The final NBS designed was a freestanding column, as seen in Fig. 8, which would house plants and circulate water. One of the schools requested a moveable and lightweight structure that could house plants, and the IAAC students responded in a creative way. Inspired by the participatory process, the students suggested creating a structure that could house pots designed by the students of Porto. Using the latest software, SubD for Rhinoceros 7, the students designed a lightweight column that

could be 3D printed using a photocatalytic material. Although the material is a plastic, its properties allow for carbon to be captured from the air adding to the multiple ecosystem services the solution can provide.

Fig. 8 3D printed prototype of column structure

In addition, the structure is designed to circulate water from the base to the top, through the inside of the column and then back down across the outside of the column, again responding to the wishes of the teachers of a self-irrigating system. The water will flow across platforms that house ceramic pots with the plants, as well as form small basins of water where birds can come and take a bath. A texture is applied to certain areas of the column to guide the water and dictate its speed flowing down so as to not damage any plants, suggested by landscape architects. The column is divided into several pieces, as pictured in Fig. 8 of the initial prototypes. This allows the column to be easily disassembled and moved from one location to another as per the request of one of the schools.

To summarize, the Porto URBiNAT experience demonstrated to the IAAC students the process of participatory design and working with experts in different fields. In addition, it taught them to consider the needs and wants of the users, while thinking from a new perspective, where the human is not the only one dictating the design. Understanding the needs of biodiversity is just as important. It is fundamental for architects and designers to reevaluate the importance of nature within our cities, and this has to start in the educational system to give students the tools, knowledge and approaches to design with or for nature by capitalizing on the expertise of others. In the example given above, the students working on the project were only architects and designers. This posed challenges for the students to evaluate and reflect upon their designs. Upon evaluating the results, the solutions could have benefitted from expertise of different fields similar to what happened during the BUILD Solutions project. However, experts were also consulted throughout the design process to support and give insight to the works developed.

III. NBS for Start-ups

NBS require many areas of expertise. Architects do not have the expertise that a botanist may have or that a business person may have to pitch the idea. Without the transdisciplinary collaboration, the result is often a surface level idea. However, when different disciplines are forced to work together, sharing ideas and their knowledge, the success of the solution is much higher.

Another methodology that was tested with NBS was that of creating transdisciplinary start-ups. BUILD Solutions was an Erasmus+ project co-funded by the European Union. It set out to create five new start-ups with NBS products. Ten architecture students from Barcelona came together with ten business students from Vienna and ten biology students from Nancy. Each discipline was to bring their expertise, to design aesthetically beautiful and functioning products. This proved to be very successful in bringing together expertise that complemented each other and could strengthen the product. Out of the five start-ups three continued to work and expand their teams beyond the program and one start-up turned into a research. The success of the start-up came down to the solution, but also the team dynamic. The program was set up in a way that after the six months, the students had to pitch their start-ups to investors. The winning start-up was then given an opportunity to further develop their idea in an accelerator program. During the program, students received expert input from the different disciplines and business partners to guide them in their start-up journey.

The course for the architecture students was set up as a two term seminar with 40 hours of teaching. Each start-up had two architectural students, and throughout the seminar the students and faculty worked closely to design aesthetically beautiful and functional products. The seminar included lectures on NBSs and the possibilities of designing with nature. During every session the start-ups progress would be evaluated from a design perspective. This program also had the challenge of COVID-19 as it took place from January 2020 to June 2020 and therefore, the students had to deal with remote teaching for half the course. Even with all the unexpected challenges the start-ups built great NBSs.

The winning start-up from the BUILD Solution program was EPICLAY. They designed a lightweight green wall system aiming at tackling the issue of air pollution demonstrated in Fig. 9. The wall tiles would provide opportunities for pollination, habitats for biodiversity and most importantly filter the air. This final prototype was completed after the program, having created several pretotypes at IAAC. The ceramic tiles have an interlocking system to allow water to flow from one tile to another and focuses on the use of epiphyte plants selected by the biologists. The design of the tiles was achieved through parametric design software and the molds were digitally fabricated by the IAAC students. EPICLAY went on to win numerous awards with their solution as it differed from the conventional green wall systems that everyone is used to, and the strong pitches developed by the business students.

Fig. 9 EPICLAY wall tile prototype

Fig. 10 aeroSQAIR render of the first prototype

The second successful start-up was aeroSQAIR, a start-up tackling indoor air pollution specifically in metro stations using moss. They designed a series of panels, as seen in Fig. 10, which could house the moss and help to purify the air by capturing harmful particles. The moss panels were parametrically designed and digitally fabricated with a CNC milling machine by the IAAC students. Beyond the program they continued to work with moss experts to further test the idea and, too, won numerous prizes for their solution thanks to the business students.

Finally, C:aire was the third successful start-up to go beyond the program. The parametrically designed column, Fig. 11, behaved as an air purifier for indoor air pollution. Pockets within the column housed plants, while a bio-filter created from bacteria was located within the column. To maximize the air filtration capacity, this column was also 3D printed using photocatalytic material. Again, the design and solution proved to be very successful and was exhibited on several occasions, as well as winning several prizes.

The success of the start-ups was very much down to the transdisciplinary teams. Not only did they have to work in transdisciplinary teams, but also across borders. This program truly simulated what it would be like to run a start-up from different locations with different experts. Both the feedback from the students and the success of the start-ups on the international stage demonstrated the demand and need for NBSs, as well as the public's interest. Like all programs, the students also faced their challenges, but they were able to overcome these and achieve beautiful results.

A fundamental aspect to the success of working in transdisciplinary groups, is creating a common language between the different disciplines. For biologists and architects, NBSs is a term that is heard frequently; however, for business students it can be a relatively new term. Having the exposure to different disciplines as a student prepares them for working on these kinds of solutions professionally. In addition, creating a healthy sense of competition between the start-ups gave them an extra drive to achieve their goals. Educational strategies need to adapt with the times, and to the challenges and solutions the world needs. Architecture is no longer about just designing buildings and therefore, curricula need to adapt and take this into consideration to keep up with the changing needs.

Fig. 11 C:aire 3D printed first prototype

IV. Results

As times change, it is also fundamental for education to change with the times. Since the European Commission published in 2015 the final report titled *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions and Re-Naturing Cities,* there has been a big emphasis on exploring the possibilities of NBS in architectural and urban design. This report has been driving research and innovation within the field of NBS in relation to architecture and urbanism [10]. To deal with the challenges our cities are facing and will face in the near future, it is very important to give students the tools and knowledge they need to design solutions for mitigation and adaptation. Without being exposed to transdisciplinary and participatory processes, students will not be able to understand how to integrate and work with different information.

During the URBiNAT Porto seminar, it was noticed that the students struggled to fully understand a participatory co-design process. It was a challenge for them to have a brief that would need to evolve and adapt based on feedback from the inhabitants of Porto and experts. Specifically, working with the feedback from 8–12-year-olds was an aspect none of the IAAC students had dealt with before. However, this was fundamental for the IAAC students to understand the social aspects of designing NBS.

While the IAAC students themselves were all architects or designers, they did receive feedback directly or through the seminar faculty from a series of experts in the fields of 3D printing, botany and landscape architecture. As architects they collaborated in a context where inputs from other disciplines shaped their solutions. By integrating the feedback and inputs, the designs could be pushed further, especially in relation to the use of plants and moss. In this case, the groups of architects would have benefited greatly from having a group member with expertise in plants. However, overall, the results were well thought through and with some fine-tuning from the experts, the solutions designed by the students are and will be implemented.

On the other hand, BUILD Solutions posed other challenges as most of the architecture students had never worked on projects with another discipline. Challenges included creating a common language where the different disciplines would understand the vocabulary the others used, and understanding the workflow in different disciplines. However, the success of the products developed came down to the different expertises complimenting each other and learning from one another. The group dynamic was fundamental to the start-up's success. While both seminars proved to be successful in creating implementable NBS, there is still a lot to learn about how transdisciplinary teaching can further push the world of architecture and design.

V. Further Research in Transdisciplinary Education for NBSs

Furthering the exploration of how education can be shaped in the field of NBSs, IAAC continues to test strategies with students to implement NBS in our cities through various seminars and programs. Green Skills for Cities is an Erasmus+ project co-funded by the European Union [11] where architects, botanists, technologists and business students are brought together, to firstly learn from the other disciplines, and secondly to design NBSs for urban challenges that have been identified by municipalities. The learners are located in three cities across Europe, Barcelona, Genova and Vienna and are working on common challenges identified by the municipalities of all three cities. The common urban challenges are water management and increased temperatures which also take into consideration the Sustainable Development Goal- climate action. The goal of this project is to give learners the skills and knowledge to work in a public body such as a municipality and be able to implement NBSs.

Two types of programs have been designed under Green Skills for Cities, the first a long-term program which lasts 6 months and secondly, a short-term program taking place in one week. The structure of the long-term program is as follows. The trainers of each discipline will provide a set of resources for the learners of the other disciplines to study, using the flip teaching methodology. Then, the learners will carry out a series of activities for them to practice the knowledge that they have gathered. The students will then come together for an intensive 3-day practical workshop where they will design NBSs for the city of Genova. The sites have been chosen by the municipality of Genova and the final goal will be for the students to pitch their designs to the municipality. The students will have the opportunity to visit the sites while in Genova, conduct research and interviews and then work on the designs and pitches. In this case, the architecture students will work more with strategies

and simulation software rather than prototyping. The short-term program will be a condensed version of the long-term program with two days of theoretical work and three days of practical work. In the short-term program students will work on solutions for the city they live in. Unlike in the solutions developed in URBiNAT and BUILD Solutions, Green Skills for Cities works at a much larger scale, the city scale, and provides new opportunities and challenges to the students. The Green Skills for Cities program will be implemented throughout 2023. Understanding how NBSs can be taught to students at different scales with perspectives from different disciplines will be fundamental in giving the students a holistic understanding.

Furthermore, in a continuation of the BUILD Solutions program, Urban Shift [12] follows on the success and learnings of creating transdisciplinary start-ups. Urban Shift is an Erasmus+ project co-funded by the European Union with the goal of creating 10 start-ups that are aiming to help achieve the goals of the European Union Green Deal. The first round of the educational program is underway with architecture, business and media students as well as students taking part in vocational education. The six-month long program will provide students with the knowledge and support they need to launch a start-up. Within the architectural course, which includes 40 hours of teaching, a class will be integrated on designing with and for nature to give the students an idea of what can be achieved when considering nature as a tool and client. In addition, they will receive advanced training from the business partners that make up the consortium. The start-ups will be tackling the challenges of urban heat island and climate, and food waste and circularity. It will be up to them to decide what kind or product they design. Unlike BUILD Solutions, they are not tasked with creating a NBS, but given the challenges being addressed, it is expected that some start-ups will produce NBS. Bringing together students from different disciplines ensures well rounded start-ups and brings different perspectives that architecture students may not have considered before, especially the business perspective. This creates added value in architectural education.

VI. Conclusion

Through these programs, IAAC is able to address the lack of expertise on NBS in the fields of architecture and urbanism to bring sustainable solutions to the labor market and implement them. With the help of transdisciplinary education, architecture students are exposed to fields such as botany, business and social science, and together they are able to develop solutions that address the urban climate challenges. When students graduate and work in offices or start-ups, they will need to work with different disciplines and municipalities. Therefore, it is fundamental that students are given the tools and the exposure to the different fields throughout their education. This provides the foundation for future collaborations and provides an appreciation for different disciplines.

In the initial stages of the programs, students have a limited knowledge of a NBS, but through the participatory process or interdisciplinary teams, students come up with solutions that can be implemented and can have an impact. When it comes to NBSs, the most fundamental aspect of achieving success is testing over and over again. Scale, too, is a fundamental aspect. Whether it is working at the prototype level like in URBiNAT and BUILD Solutions, or working at an urban planning scale like in Green Skills for Cities, they are both fundamental in achieving successful NBSs. Designing with or for nature is a complex process that requires persistence, but these are skills that students can take to their professional careers and reshape the way in which we design cities.

Acknowledgment

URBiNAT NBS for Porto was developed within the "URBiNAT" project, with funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 776783. The team was composed of this paper's authors, the Advanced Architecture Group and IAAC students of the Master in Advanced Architecture program 2021. The "BUILD Solutions" project, co-financed by the Erasmus+ Program of the European Union. The team was composed of the Advanced Architecture Group and IAAC students of the Master in Advanced Architecture program 2019. The "Green Skills for Cities" project, co-financed by the Erasmus+ Program of the European Union. The team is composed of the Advanced Architecture Group and IAAC students of the Master in Cities and Technology program 2022. The "Urban Shift" project, co-financed by the Erasmus+ Key Action 2 Partnerships for Innovation Alliances for Innovation 2021 Program of the European Union. The team is composed of the Advanced Architecture Group and IAAC students of the Master in Advanced Architecture program 2022.

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