World Transactions on Engineering and Technology Education
Vol.22, No.4, 2024

A laboratory for adaptation of urban areas to climate change: flooding resilience and climate-sensitive waterfronts

Jakub Gorzka & Lucyna Nyka

Gdańsk University of Technology
Gdańsk, Poland

ABSTRACT: New architectural approaches for adapting cities to climate change demand a comprehensive and integrated perspective. One of the complementary methods of educating students involves creating laboratories dedicated to specific topics, implemented within a network of collaborating universities. The Laboratory for Adaptation of Urban Areas to Climate Change, focused on flooding resilience and climate-sensitive waterfronts as vital topics, brought together a multidisciplinary expert group in architecture, urban planning, spatial planning, sociology, journalism, and others. Students and young researchers working together were encouraged to delve into a more holistic approach to the issue of climate-sensitive waterfronts, yielding numerous benefits compared to what is typically offered within the framework of separate subjects delivered within a standard curriculum. Doctoral candidates, who are both third-degree students and researchers, could experiment with applying their thesis concepts by collaborating with students in data-driven and creative research-by-design investigations.

INTRODUCTION

Climate change consequences have triggered new scopes of research and education focused on strategies for resilient cities. The study programmes' cores and curriculums of various architecture schools are predominantly focused on sustainability and include issues related to the adaptation of urban spaces to climate change [1-3]. This is driven by regulatory documents and subsequently published alarming reports revealing the scale of the crisis and indicating paths towards regenerative transformation [4]. However, the dynamically emerging challenges demand going beyond the rigid framework of pre-designed courses and call for the introduction of new kinds of innovation-driven academic initiatives that foster high quality research-based education [5].

One such complementary initiative involves setting up laboratories dedicated to specific set of issues, implemented within a network of collaborating universities [6][7]. These laboratories, often related to ongoing international research projects, integrate international groups of students and researchers in experimental inquiries into particular topics, enabling the participants to gain new sets of competencies [8]. At Gdańsk University of Technology (Gdańsk Tech), spanning the years 2019-2023, the Horizon 2020 (H2020) SOS Climate Waterfront project was conducted, which gave impulse to the initiation of the Laboratory for Adaptation of Urban Areas to Climate Change, with flooding adaptability and climate-sensitive waterfronts as important topics of research investigations. This initiative involved students, doctoral candidates, non-academic specialists and academic teachers from several European universities in mutual collaboration. The incentive was to engage all involved groups in creative reframing the problem and facilitate its interpretation from different perspectives.

The urge toward developing innovative solutions for urban waterfronts emerges from unprecedented challenges, mainly the increasing probability of occurrence of pluvial, fluvial and coastal flooding. In these circumstances, it is imperative to reassess current planning strategies for vulnerable areas. The forces that drive urban transformations are often contradictory. The problem revolves around such dilemmas as whether to expand cities in flood-prone directions at all and, if so, how to ensure safe and high-quality urban spaces and landscapes [9][10]. It should be acknowledged that cities undergoing constant urban transformation processes can be viewed as dynamic systems [11]. This is particularly visible on the land-water boundary, where hard lines of embankments are often re-designed into transition buffering zones [12].

Programming and implementing effective adaptation policies for urban areas vulnerable to the effects of climate change, is a task for both municipal agencies and the academic community [13]. How to operate within regulatory planning documents and contribute to the development of new ones? The new notions, such as flexibility, dynamism, scenario planning, and adaptability of urban spaces to different levels of water have entered the architectural and urban vocabulary [14][15]. In this context new questions emerge: what kind of adaptive flood-resistant architectural structures can be introduced in vulnerable areas? May they contribute to the accessibility of urban waterfronts and adaptability of public spaces to different levels of water? Moreover, how they interact with energy retrofitting policies or may contribute to supporting ecosystem services - all these questions need careful consideration. Finally, the most important question is how to prepare students to new challenges basing on new climatic data.

The Laboratory for Adaptation of Urban Areas to Climate Change was conceived as a win-win initiative for all participating groups. In particular, students were encouraged to negotiate between different, often contradictory, forces and delve into a more holistic approach to the issue of climate-sensitive waterfronts, in comparison to what they are usually offered within the framework of separate subjects delivered within the standard curriculum. Doctoral candidates, who were both third-degree students and researchers, could experiment with applying their thesis concepts by collaborating with students in data-driven and creative research-by-design investigations. Also, academics gained new experiences of working in the international context related to the implementation of research projects.

METHODOLOGICAL FRAMEWORK

The laboratory, functioning within an international collaboration between universities from Sweden (KTH Stockholm), Italy (Sapienza University of Rome), Portugal (Lusophone University of Humanities and Technologies, Lisbon), Greece (Aristotle University of Thessaloniki), Turkey (TOBB University of Economics and Technology, Ankara) and Poland (Gdańsk Tech), brought together a multidisciplinary expert group in fields, such as architecture, urban planning, spatial planning, sociology, journalism, and others. Workshops held at various cities allowed students working together with early-stage researchers to familiarise themselves not only with different case studies, but also with various approaches to the resiliency of cities and led to the exchange of experiences on modes of research-empowered education in different parts of Europe [16].

The methodology of the laboratory was divided into four stages (Table 1), with each stage's scope developed in advance, although evolving in parallel with the outcomes obtained at each stage. Within the laboratory, students had the opportunity to learn about different levels of activities, educational approaches, forms of communication, research methodologies, and ways of presenting research findings and design tasks.

Table 1: Diagram of the laboratory's operating method.

W →	CS →	RD →	T
Workshops	Case study	Research by design	TAIA*
Stakeholders' visits Presentations Communities Discussions Exhibitions Lectures Events Art	Photo acquisition Plans analysis Hand drawing Master plans Onsite visits Maps	Hand drawing Presentations Simulations Discussions Exhibitions Animations Modelling Design	Government Waterscape University Porosity Heritage Urgency

*Target-applied interventions assessment - evaluation method developed by B. van de Klundert, B. Donmez, D. Zouni, J. Józekowski, J. Gorzka, M. Koning and R. Issa at SOS Climate Waterfront workshops, Rome, Italy 2023.

The first stage involved workshops where students explored various aspects of urban transformations and gained knowledge of selected research methods, including historical research, qualitative research, correlational research, experimental and quasi-experimental research, simulation research and the case-study method that usually combines several strategies - all characteristic for the domain of architectural investigations [17].

Activities at this stage included stakeholder visits, lectures, presentations, discussions, events, exhibitions and participation in art events. In the next stage, participants focused on the creative interpretation of selected case studies. Divided into groups, they built their individual insights into specific urban territories and, under the supervision of multidisciplinary international experts, began to identify the challenges and problems of particular sites, using the knowledge acquired about different research methods. Activities in this stage ranged from traditional onsite visits, photo acquisition, and hand drawing to map, plan and master plan analysis. Using the skills acquired, students conducted thorough analyses and identified the issues characteristic for the assigned case studies, which provided a solid foundation for their further work. This creative approach allowed for selecting diversified leading themes for particular locations, which led to revealing the complex and interrelated aspects of adaptive urban strategies to face climate change. For instance, in Rome, the leading challenge was to creatively support public access to riverine areas and not to exacerbate existing risks related to flooding; in Stockholm, the main research topic concerned energy balance and rainwater retention; and in Gdańsk, it focused on the built heritage in the face of water level rise scenarios.

The next stage of the adopted methodology was research by design. In this unique methodological approach, architectural and urban designs are both conceived as creative responses to research questions and inspirations for re-thinking initial presuppositions. At this stage, students utilised all the skills previously acquired, liking diversified fields of knowledge and largely extending the individual school's curricula.

The final stage of the laboratory's activities was the joint evaluation of the results obtained. A multidisciplinary expert team from different academic and non-academic centres developed an evaluation method called target-applied interventions assessment (TAIA). This method allows for an easy, graphical assessment of case study issues and the introduced solutions, making it possible to compare them against others. By obtaining uniform graphs, it is possible to analyse and compare the effectiveness of the proposed concepts on the background of the most critical issues characteristic for particular locations.

Heritage	Waterscape	Porosity	Urgency	University	Government
Heritage	Heavy rain	Build up environment	Short term	Study	Indicate
Non heritage	Drought	Natural	Long term	Offer	Listen
Private	River	Solid	Urgent	Participate	Stimulate
Public	Sea	Porous	Optional (not obligatory)	Facilitate	Force

Figure 1: Target-applied interventions assessment (TAIA) - the method and example (graphics by J. Gorzka).

RESULTS

More than 50 students and 50 doctorate candidates from six universities located in different European countries participated in the activities of the Laboratory for Adaptation of Urban Areas to Climate Change. Participation in workshops at various European universities significantly enhanced students' and young researchers' experiences by exposing them to diverse approaches to research, learning and defining climate adaptation strategies.

The first stage of the workshops was described by students as *knowledge in a nutshell*, presented in a very accessible and non-binding way. They particularly appreciated the opportunity for equal and inclusive conversation with both experts and direct users, or specific communities benefiting from the interventions already implemented in cities. Meetings with independent artist groups, such as the Blivande Commune in the post-industrial areas of Frihamnen in Stockholm, were especially attractive. Artists associated with this initiative created an inspiring venue for individual and group development on the premises of revitalised post-industrial spaces. They activated residents and surrounding communities through exhibitions, shows and craft café meetings. The case studies analysis stage was the most formal part of the laboratory programme. Despite its pre-defined format, students valued the broad range of possibilities and carefully selected case studies for further development.

The output of the workshops presented intriguing findings in the field of urban adaptation of vulnerable areas to climate change. First of all, it was found that building in flood-prone areas is feasible, with amphibious structures presenting the greatest adaptive potential to changing water conditions. Participants also observed numerous possibilities for adapting heritage buildings, particularly though buoyant foundation retrofitting. Floating buildings and public spaces were also identified as climate-resilient solutions. This ensures that city centres, particularly those located by the water and vulnerable to fluctuating water levels, do not have to halt development. The results of the workshops confirmed that flood barriers and other hard engineering structures are not the only solution to water fluctuations. Various nature-based solutions used for storm water management, as well as floating and amphibious retrofitting technologies allow for building and adapting existing structures to the risk of flooding.

Simulations to explore the relationship between built structures and water levels were developed using architectural design methods, presenting two different approaches. In the simulation for a location in Rome, the authors used available situational and elevation maps in vector format (.DWG) and 3D terrain maps generated through the cadmapper.com portal, which organises data from public sources like OpenStreetMap, NASA and USGS into CAD files. They analysed the waterfront's topography and created a conceptual waterfront development project to create a 3D model of the location using AutoCAD LT 2021 and SketchUp Pro 2022 software. This precise 3D model, combining the designed urban space with the natural terrain, was tested with simulations of water level changes. An animation showing the rising water levels was created in Sketchup for presentations, while visualisations at one-meter intervals were prepared for publication. These simulations helped to evaluate the effectiveness of the proposed design solutions. The conducted simulations showed that the use of amphibious and floating structures on a multifunctional waterfront allows for simultaneous public use of the area, while also enabling it to absorb significant amounts of water.

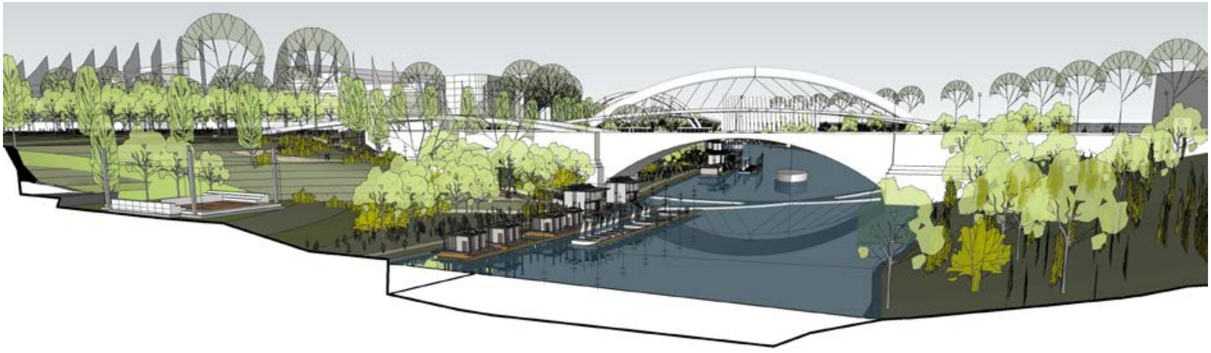

Figure 2: Rome case study - exemplary 3D cross section (modelling and graphics by J. Gorzka and J. Józekowski).

Figure 3: Rome case study - flood resistance. Simulation of the Tiber's waterfront functioning, showing that despite changes in water levels, it is possible to maintain full functionality and usability of the facilities (modelling and graphics by J. Gorzka and J. Józekowski).

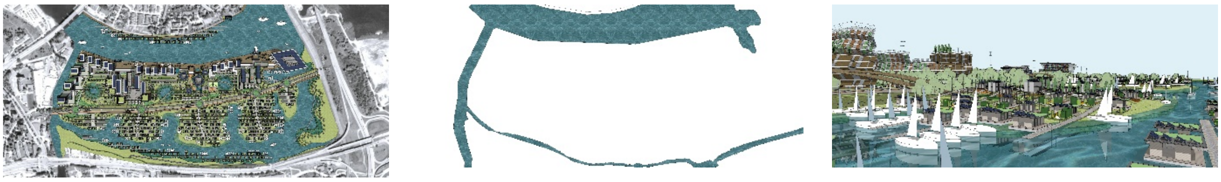

Figure 4: Gdańsk case study - heritage. Adapting post-industrial areas with respect for the site's history: land development plan, the area, modelling of the new space (modelling and graphics by J. Gorzka).

Figure 5: Gdańsk case study - water level rise adaptability. Simulation of the ability to accommodate rising water levels without compromising the designed land development, thanks to the use of elevations and floating and amphibious architecture (modelling and graphics by J. Gorzka).

The approach for the Gdańsk location was different since, unlike Rome, the area was a generally flat, low-lying terrain. The only high, regulated waterfront was on the riverside, used as a mooring place, while the rest of the area sloped gently towards an unregulated, seasonally flooding stream. Existing situational and elevation maps in DWG format were used, along with terrain models generated through the same portal, to prepare a base for designing both the urban planning of the waterfront areas and the more varied terrain. The design included a space for water overflow, allowing the area to absorb large amounts of water during floods, and natural elevations were created to safely accommodate traditional buildings, as well as amphibious and floating structures. As with the Rome case, a 3D model of the entire development was prepared using AutoCAD and Sketchup, resulting in an animation and drawings visualising different water levels at one-meter intervals.

The TAIA analytical method enabled the comparison of applied interventions. This comparison revealed that the majority design solutions involved engaging waterfront areas and even the water zones themselves, along with proposals for amphibious and floating structures. These solutions not only provided additional urban attractions including thriving water-related public spaces, but also enabled construction in areas that would typically be unsuitable for traditional development, such as floodplains or other urban areas vulnerable for water level fluctuations. Some participants even concluded that the most resilient structures to water level changes are those initially placed in the water. However, the final evaluation of the proposed solutions revealed that amphibious foundations offer the greatest potential for urban extensions. The possibility of applying these solutions to heritage buildings was also discussed, and existing literature confirmed that this is indeed feasible and practiced worldwide [18].

Discussions revealed that the opportunity to participate in the laboratory activities was highly valued by students. The participants particularly appreciated the opportunity to work in an international context, which facilitated their understanding of the diverse hydrological and environmental data for each location, as well as the social, demographic, legal, and other factors influencing the urban and architectural rationale for each project. A standardised evaluation method, developed during one of the workshops, was also appreciated by students, as it facilitates understanding how their work could be compared to solutions developed by other groups for other case studies conducted in other workshop locations. The activities of the laboratory participants were not limited to developing and then evaluating together the design solutions. Students also proposed the graphic layout for presentations, publications and exhibitions, and developed comprehensive marketing strategies accompanying the design solutions, including brand names and logo designs.

Besides strictly educational benefits, this interdisciplinary co-operation has resulted in numerous research findings, including a set of recommendations for future research directions. First of all, it was observed that the design of coastal zones in Europe and worldwide considers several key factors, including environmental, economic, social, cultural and legal-regulatory aspects that cannot be isolated, as they are mutually interrelated. Environmental considerations highlighted by the European Water Framework Directive (WFD) set ambitious goals for achieving good water status by 2015 or, at the latest, by 2027. The WFD emphasises the protection and restoration of clean waters across the European Union, underlining the need for near-natural water bodies and ecosystems. It also stresses the necessity for integrated management of water bodies to achieve good ecological status in all surface waters.

Conclusions drawn from the laboratory studies confirmed, that floating buildings and public spaces may contribute to achieving this goal through integration of green infrastructure that can lead to water retrofitting and enhance shallow water biodiversity. As introductory studies reveal that the location of amphibious settlements allows for sustaining and even regenerating precious floodplains ecosystems.

Since climate change increases the risk of flooding in waterfront cities, flood protection measures are the most important. Waterfront design must include adaptive strategies, such as elevating land, constructing flood barriers, and implementing floating or amphibious architecture. Moreover, designing waterfront zones should consider nature-based solutions, such as water retention systems, green infrastructures and flood management technologies to reduce flood risks and minimise damage. Adaptive planning and design involve creating flexible and resilient infrastructure and built environments that can sustain without damage in changing climatic conditions, including floating and amphibious architecture. The research by design method offered interesting insights into changing urban morphologies of chosen locations (particularly the Gdańsk and Rome case studies) resulting from water level fluctuations.

New sets of questions however appear, such as how to provide continuity of public spaces and enhance walkability in the areas on the land-water interface and how to reinforce the role of floating constructions as urban attractors. Other important issues concern the energy efficiency of floating structures, particularly their ability to operate off-grid during periods of disconnection from municipal infrastructure, as there are still significant gaps in this field [19]. Moreover, comparative studies on the benefits of implementing floating and amphibious architecture in specific hydro-sensitive locations are still scarce.

CONCLUSIONS

The work stages proposed within the laboratory for addressing flooding adaptability and climate-sensitive waterfronts allow students to acquire knowledge, experiment with research by design method, create and present their own design solutions. Within the laboratory, students familiarised themselves with both research and design methods that would typically require learning across several different disciplines and courses. As a result, they could use their acquired skills to professionally present their concepts in jointly organised conference panels and exhibitions. The activities undertaken enriched the students' toolkit for both preparing analyses and directly executing their own projects. The proposed method for evaluating applied solutions - target applied interventions assessment, was highly appreciated by students as an added value in the process.

Owing to this comprehensive and interdisciplinary programme, students improved their skills in many areas. Participation in conferences helped them become comfortable with final presentations in front of diverse audiences, including peers, academics, local stakeholders, cultural institutions' representatives, artists and residents. Discussions and working in the international teams, as well as consultations with specialists from various fields, encouraged students to go beyond separate disciplines while defining project goals. Working within laboratory provided students with additional tools for different stages of the work: from defining briefs for the projects, translating them into architectural and urban solutions, to communication and formulation of further academic goals, including choosing the topics of Master thesis or, in some cases, doctoral dissertations. The laboratory also enriched the work of young researchers offering them a creative environment where research concepts were investigated through experimental and interdisciplinary architectural and urban projects. Finally, the joint laboratory's initiatives have given rise to new educational and research initiatives of the involved universities, bringing further benefits to the new cohorts of students.

REFERENCES

1. Schiano-Phan, R. and Soares Gonçalves, J.C., Sustainability in architectural education - editorial. *Sustainability*, **14**, 10640 (2022).
2. Martínez-Ventura, J., de-Miguel-Arbonés, E., Sentieri-Omarrementería, C., Galan, J. and Calero-Llinares, M., A tool to assess architectural education from the sustainable development perspective and the students' viewpoint. *Sustainability*, **13**, 9596 (2021).
3. Burda, I. and Kołodziejczak, J., Adapting education to a changing climate: preparing architecture students for climate-resilient design. *World Trans. on Engng. and Technol. Educ*., 21, **4**, 235-240 (2023).
4. Monteiro, A., Ankrah, J., Madureira, H. and Pacheco, M.O., Climate risk mitigation and adaptation concerns in urban areas: a systematic review of the impact of ipcc assessment reports. *Climate*, **10**, 115 (2022).
5. Nyka, L. and Marczak, E., Frontier education for a sustainable future - speculative design in architecture as a transdisciplinary experiment. *Global J. of Engng. Educ*., 25, **1**, 6-11 (2023).
6. Vitková, L. and Šeligová, A., Joint study programmes based on thematic modules. *Global J. of Engng. Educ.*, 25, **3**, 156-162 (2023).
7. Borucka, J., Parrinello, S., Picchio, F. and Szczepański, J., Use of innovative digital laboratories to train a new generation of architects: integration of education, practice and research for digital cultural heritage. *Global J. of Engng. Educ*, 26, **2**, 88-94 (2024).
8. Ilkovičová, L., Ilkovič, J. and de Oliveira, M.B., Interdisciplinary education in the architectural design of engineering structures. *Global J. of Engng. Educ.*, 24, **3**, 171-178 (2022).
9. Burda, I. and Nyka, L. Providing public space continuities in post-industrial areas through remodelling land/water connections. *Proc: IOP Conf. Series: Material Science and Engng*., 245, **8**, 082037 (2017).
10. Cin, F.D., Hooimeijer, F. and Silva, M.M., Planning the urban waterfront transformation, from infrastructures to public space design in a sea-level rise scenario: the European Union Prize for Contemporary Architecture case. *Water*, **13**, 218 (2021).
11. Sulistianingsih, A.S. and Marji, Environmental awareness in project-based urban and settlement architecture learning, *Global J. of Engng. Educ.*, 25, **1**, 46-53 (2023).
12. Burda, I.M. and Nyka, L., Innovative urban blue space design in a changing climate: transition models in the Baltic Sea region. *Water*, **15**, 2826 (2023).
13. Penning-Rowsell, E., Floating architecture in the landscape: climate change adaptation ideas, opportunities and challenges. *Landscape Research*, 45, **4**, 395-411 (2020).
14. Nyka, L. and Burda, I., Scenario-planning solutions for waterfront flood-prone areas. *Global J. of Engng. Educ.*, 22, **3**, 149-154 (2020).
15. Woźniczka, A. and Widera, B., Developing sustainable resilience through forecasting and backcasting in architectural education. *World Trans. on Engng. and Technol. Educ.*, 20, **1**, 39-44 (2022).
16. Nyka, L., Azadgar, A., Larsen, K. and Ressano Garcia, P., From creative writing, virtual environments to nature-based solutions: linking research and education to facilitate transition from sustainable to regenerative cities. *Global J. of Engng. Educ.*, 26, **2**, 75-81 (2024).
17. Groat, L. and Wang, D., *Architectural Research Methods*. Hoboken, New Jersey: John Wiley & Sons, Inc. (2013).
18. English, E.C., Chen, M., Zarins, R., Patange, P. and Wiser, J.C., Building resilience through flood risk reduction: the benefits of amphibious foundation retrofits to heritage structures. *Inter. J. of Architectural Heritage*, 15, **7**, 976-984 (2019).
19. Gorzka J., Karczewski, A., Nyka, L., Litwin, W., Matej-Łukowicz, K., Nawrot, N. and Piątek, Ł., Zero emission, off-grid, autonomous houseboat - a case study for selected locations in Europe. *Polish Marit. Research,* 31, **3**, 42-60 (2024).