Climate adaptation in design education: applying a four-step research by design strategy

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The purpose of this paper is to discuss the insights gained by testing in a design studio a particular research-by-design strategy, focusing on the generation of innovative solutions for climate change adaptation. The strategy is based on the Design Thinking Process and has been applied in the climate adaptation design studio, which took place in 2022 at a Master of Architecture degree program in the Netherlands. The case study area was the Zernike university campus in Groningen, the Netherlands, which is situated in the verge between the city and the surrounding rural landscape, facing the urgent climate change challenges of the wider region, mainly floodings due to increased frequency of rainfalls and sea level rise. Furthermore, the area faces particular challenges, such as the increasing demand for serving additional needs, beyond the current educational and business related functions, such as (student) housing. Three indicative design research projects were selected to illustrate the tested research-by-design strategy, while systematic input has been collected from the participating students regarding the impact of this strategy on their design process. The results reveal that this strategy facilitates the iterative research-by-design process and hence offers a systematic approach to convert the threats of climate change into opportunities by unravelling the potentials of the study area, resulting in place-based, innovative and adaptive solutions.

Keywords: climate adaptation; research-by-design; design thinking process; design education; university campus

1 Introduction

Climate change's uncertainties and related wicked problems (Rittel & Webber, 1973) necessitate new spatial solutions for resilient cities and landscapes. Designers and planners need to adapt to the shifting needs and dynamic conditions of a world that is evolving very quickly. To do this, comprehensive and transformative design methodologies are required, allowing for radical climate adaptive, place based solutions (Davoudi et al., 2009). As mentioned in (Pons, 2008), introducing climate change understanding and climate adaption approaches in design education, can catalyse spatial interventions and transitions that are not dictated by fear, and where uncertainty is embraced. That constitutes a major challenge for architectural, urban and landscape design education.

Design studios, workshops and charettes have received particular attention as key elements of design education and practice. They are mainly characterized by experimentation with climate adaptation design solutions in various scales (Adegun & Olusoga, 2020), with the ultimate goal of educating sustainability-literate designers (Micklethwaite & Knifton, 2017).

To that end, research-by-design methodological approaches receive increasing attention and interest into design education (Cattaneo et al., 2019; Charoenlertthanakit et al., 2020). The main distinction between research-by-design and design research lies in the emphasis and focus of each approach. Research-by-design primarily involves conducting research through the act of designing, while Design Research investigates broader aspects of (the impact of) design, by using various research methods. Usually when research-by-design methodology is applied within the design educational context, it is approached within a non-linear, yet integrated, process. Specifically, there is an important body of literature on research-by-design that focuses on descriptions of the process, such as the pre-design and post-design phases, the iterative nature of the process, and the divergence and convergence phases (Boomen et al., 2017). Additionally, the experiences and design outcomes of studios in a university setting where research-by-design has been used (Adegun & Olusoga, 2020; Amenta & Qu, L., 2020; Boomen et al., 2017; Dubois et al., 2015; Lenzholzer & Brown, 2013) are characterized by a better systemic understanding and scenario thinking.

In an effort to provide clear guidelines regarding the applicability of research-by-design to complex design and planning problems related to climate adaptation (Cattaneo et al., 2019; Amenta & Qu, L., 2020), a four-step strategy (Psarra et al., 2021) has been developed based on the iterative Design Thinking Process diagram developed by the Future Urban Regions lectureship in the Netherlands (Boomen et al., 2017). It consists of four main iterative loops of research-by-design, filled in with specific directions on how to approach a study area, analyse it, and formulate climate adaptation ideas, concepts, projects, and designs, by converting threats into opportunities. Each step of this strategy entails specific analytical questions, design approaches, and criteria which can serve as anchoring points and that can offer guidance to the researcher designer.

Specifically, this four-step strategy has been developed in a research and design studio, which took place in 2020 at a Master of Architecture degree program in Groningen, the Netherlands (jointly organized with the Master of Architecture program at Queen's University Belfast, Northern Ireland). Designing for resilience to the effects of climate change on the ultra-low-density region of the Lake District, UK was the theme of that studio.

In 2022, a follow-up climate adaptation design studio took place at the Master of Architecture in Groningen, aiming at applying and testing the four-step strategy within an urban context this time, and in particular within the smaller and more strictly defined area of the Zernike university campus in Groningen. This area is situated in the borderline between the northern part of the city and the surrounding rural area of the Groningen province. The four-step strategy has been applied in order to further investigate the extent to which this strategy can systematize and enrich the design process of architectural students and their effort to come up with climate adaptation solutions in a smaller scale and within an urban context.

The goal of this paper is to discuss the gained insights from applying this four-step strategy within an urban and strictly demarcated case study area. Indicative research-by-design student projects have been selected to demonstrate the way that this strategy influenced the design process. Furthermore, students feedback on the four steps of this strategy is discussed.

The outline of this paper is as follows. First, the context of this study is explained by briefly introducing the research-by-design methodology and the four-step strategy. Secondly, a brief description of the study area is provided, the three indicative design research projects, originating from the aforementioned design studio on climate adaptation, are presented, while students' feedback on the four-step strategy is also reported. The way the four step strategy is reflected in the three examples and the insights gained by the experiences of this design studio are discussed in detail and from these the main conclusions are drawn.

2 Research-by-design in climate adaptative design education

2.1 Research-by-design

The research-by-design method situates "design" in the core of the probing process to explore and identify opportunities for improvement (de Queiroz Barbosa et al., 2014; Van de Weijer et al., 2014). This is achieved via spatial explorations, such as sketching, mapping, material analysis, modeling, and design artefacts (de Queiroz Barbosa et al., 2014; Hauberg, J., 2014). The non-linear process of design, based on these operational tools, creates a constant flux between the problem and possible solutions (Ramsgaard & Tamke, 2009).

While researchers and practitioners approach research-by-design differently (Van de Weijer et al., 2014), convergence, divergence, iteration, and feedback loops remain the key components that support the complex decision-making processes. The Future Urban Regions research team developed a Design Thinking Process (DTP) graphic to represent the various stages of design-based research, including strategy, idea, concept, project, design, product, and monitoring (Figure 1).

Each stage is a point of consolidation made up of a phase of divergence and a phase of convergence. In particular, as shown in Figure 1, the two primary aspects of the divergence phase are inform and combine, while the two main aspects of the convergence phase are choose and implement. The diagram's narrowed bandwidth illustrates how research increasingly narrows and becomes more targeted (Boomen et al., 2017). The act of designing generates new knowledge and potential future possibilities throughout the entire process.

The Design Thinking Process (Figure 1) constitutes the main underpinning of the four-step research-by-design strategy that has been developed in the context of this study, and which particularly focuses on the design process of climate adaptation solutions.

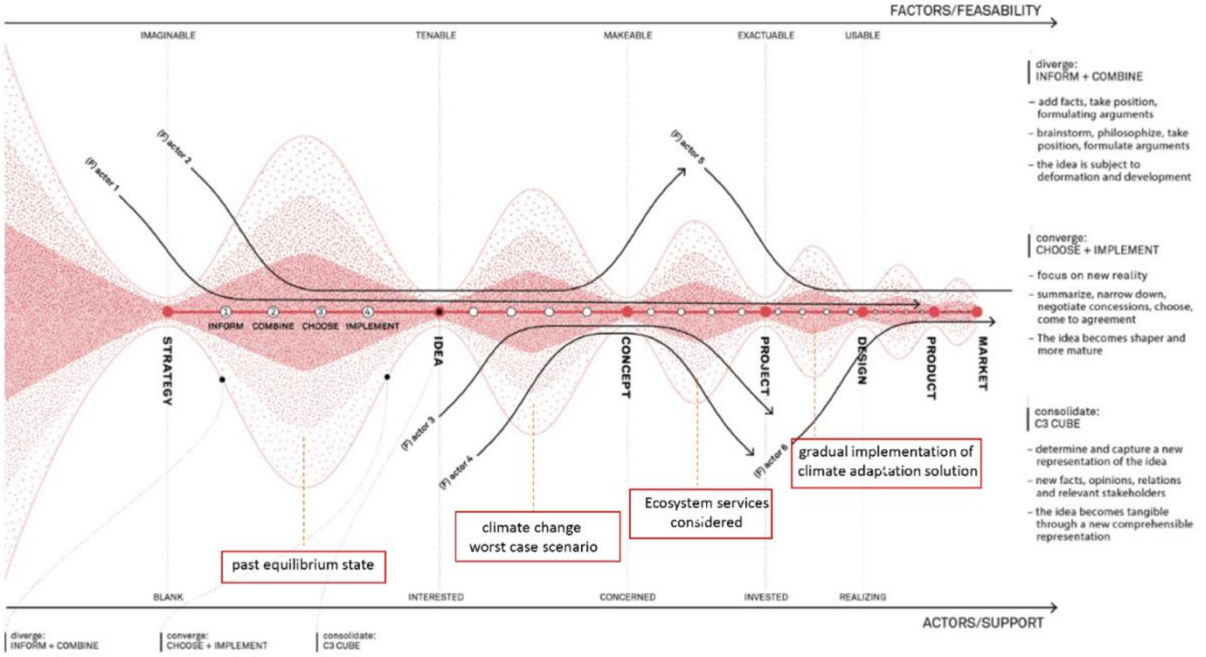

Figure 1. The suggested four-step strategy embedded in the Design Thinking Process Diagram (Boomen et al, 2014, p.128-129; Psarra et al, 2021). For citations to the four steps see text below and (Davoudi et al., 2009; Costanza et al., 2017; Hallegatte, 2009; Helmrich & Chester, 2020; Grimm et al., 1997; Wilson & Piper, 2010; Porter & de Roo, 2012; Stremke & Picchi, 2017).

2.2 The four-step research-by-design strategy for climate adaptation design solutions

The four-step research-by-design strategy consists of the following steps:

1. Approaching the study area as a complex adaptive system (Levin et al., 2013) in which the previous states of equilibrium are also investigated. The state of equilibrium refers to the conditions of the natural environment (geophysical and ecological) and the resilience of the biomes within it to natural climatic variations. The divergence phase of this step revolves around a historical analysis of the study area, oriented towards the identification of the main drivers of change. A thorough historical analysis that tracks back to moments of significant change leads to the identification of the most recent point of time when the natural (and depending on the context, also the man-made) systems were in balance (Davoudi et al., 2009; Wilson & Piper, 2010; Porter & de Roo, 2012). Based on that, the underpinning conditions, values, or concepts that enabled this equilibrium state can be identified. Then, the convergence phase of that step focuses on the selection of study area characteristics which can play a key role in the formulation of a new vision for the future (Figure 2).
2. Developing and using worst-case climate change scenario(s) constitutes the second step of the strategy. Specifically, in the divergence phase, the major climate change challenges of the study area are addressed, based on relevant data, and several pre-set future scenarios on the impact of climate change in the area are identified (Helmrich & Chester, 2020; Hallegatte, 2009). In the convergence phase, the worst case scenario(s) are developed and visualized;
3. Considering the spatial–social sphere of the study area by identifying, safeguarding, and enhancing the relevant ecosystem services (Costanza et al., 2017) in the proposed climate adaptation solution is the third step of the strategy. Specifically, in the divergence phase, a systematic spatial analysis takes place, aiming at the ecosystem services identification.

Ecosystem services are defined as the benefits people obtain from ecosystems (Costanza et al., 2017; Stremke & Picchi, 2017), consisting of the provisioning, regulating, supporting and cultural ecosystem services. Specifically, examples of provisioning services are food and water; supporting services refer to soil formation and nutrient cycling; regulating services are related to regulation of floods, drought and land degradation; while cultural services correspond to recreational, spiritual and other non-material benefits. In the convergence phase, the preferred scenario is selected and visualized.

4. The last step of the strategy revolves around the development of a gradual, phased sequence of implementation of the design solution.

Key stakeholders can be directly involved in all these four steps of the strategy.

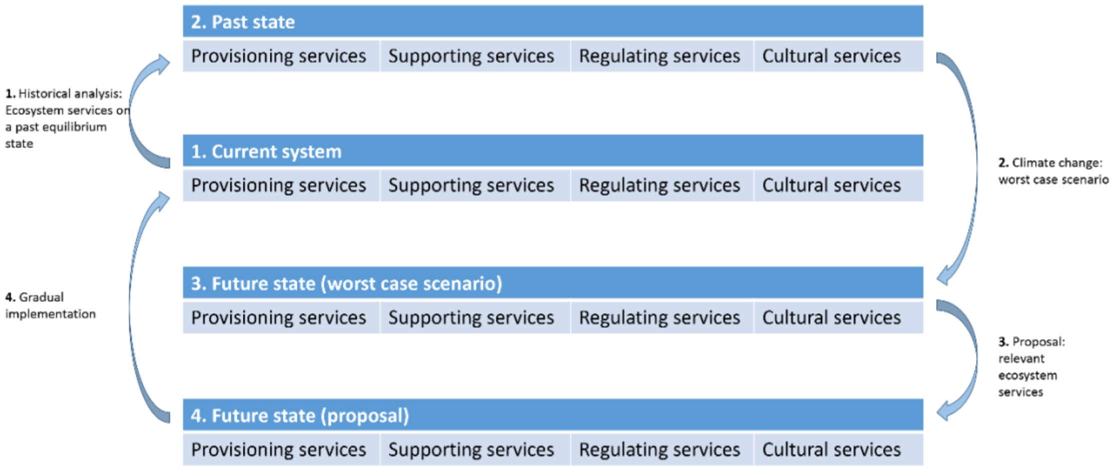

Figure 2. Diagram depicting the main steps of the research-by-design strategy (Psarra et al, 2021).

3 Results

3.1 Studio structure

The design studio focused on the Zernike university campus of Groningen, the Netherlands. The main goal of the studio was to develop climate adaptive design solutions to the direct and indirect impacts of climate change in this area (i.e., extreme weather phenomena, flooding). The students applied the four-step research-by-design strategy.

The duration of the design studio was fifteen weeks. The first five weeks were devoted to the analysis of the case study area. One student group conducted a historical analysis of the food, water and energy system of the study area (aiming at drawing conclusions regarding the identification of past equilibrium state(s)); another group identified the local ecosystem services; and the third student group studied the most relevant to the study area climate change challenges, aiming at formulating relevant worst case scenarios. This first phase of the design studio resulted in the creation of a comprehensive research atlas consisting of the most important research results. The students transformed the main analysis findings, their acquired knowledge on the theme of climate adaptation, and the spatial systemic properties of the study area into concrete individual design briefs. The design proposals are the result of elaborate experimenting, reflection on the selected guiding themes and briefs and the implementation of the iterative process of the four-step strategy.

Summing up, the design studio constituted an appropriate opportunity to study the dynamics of the study area and actually became the occasion for the further testing of the four-step strategy. It was pedagogically interesting for the students of different years of study to explore their hypotheses through the process of design and by implementing the same four-step strategy (in projects varying in scale, research focus, etc.).

3.2 Brief description of the study area

The Zernike campus area is a mixture of businesses and higher education buildings in the north-west part of Groningen (Figure 3). The University of Groningen and the Hanze University of Applied Sciences are located there, providing education to approximately 35,000 students. It is the working place of more than 4,000 researchers and employees, as well as of a big number of entrepreneurs. For the approximately 150 companies, the high-tech facilities and collaboration opportunities provide an excellent breeding ground for their products and services.

The area is quite secluded from the rest of Groningen and has its own laid-back, inclusive culture. Although appearing separate from the city, the thousands of new students arriving each year, contribute to Groningen's bustling and vibrant atmosphere. The campus itself is made up of large stand-alone buildings, each with its own architectural language. In the north of the campus, there is an equally large area of stand-alone buildings owned by private companies. Without public events, recreational spaces, shops, or housing, there is nothing to attract the public in the evenings and on weekends, when the complex becomes still and desolate. Combating this is the university sports facilities, as well as public walking routes surrounding the perimeter of the complex. Wild overgrown green areas on the eastern edge attract some homeless camping.

Currently there is no housing present but there is an intention from the municipality of Groningen and the two universities to introduce housing on campus. The main reason is the lack of sufficient student housing options in the city of Groningen. The main challenge to this end is achieving a feeling of safety and liveliness. Currently, a need for 1000-1500 rooms for people studying or working at the campus is prioritized, while corresponding services and other facilities (i.e. recreational, commercial, etc) need to also be taken into account. According to the estimations of the students of the above described design studio, in 2100, the number of expected students and residents in Zernike is approximately 65,000 students and 10,000 residents.

Figure 3. Maps of the Zernike university campus in Groningen.

The university campus of Groningen was considered a suitable case study for this studio because it provided a wide range of overarching problems and climate adaptation challenges, resulting in a great variety of student design projects. This, subsequently, also offered an appropriate opportunity to test the implementation of the four-step strategy across various student projects of different scales and themes across the full spectrum of challenges in this area. This resulted in useful insights regarding the extent to which the implementation of the strategy can facilitate the design process of the students.

3.3 Three indicative research-by-design projects

Three indicative design projects, developed in the above-described design studio, are selected to illustrate the way the four-step strategy has been implemented. In Groningen area, the most urgent problems related to climate change and extreme weather phenomena are the increased frequency and intensity of flooding (due to the increasing sea level rise and the increased frequency and intensiveness of rainfalls) and heat stress (Figures 4,5). Thus, Summers are expected to become longer, dryer and hotter and Winters and Autumns much more rainy. All the design proposals focused on these challenges, with each one emphasizing either the provisioning, or the cultural or the regulation and supporting ecosystem services, respectively (Table 1). Finally, the three design projects aimed to explore design solutions that would enhance the resilience of the study area, with a particular focus on adaptability and transformation.

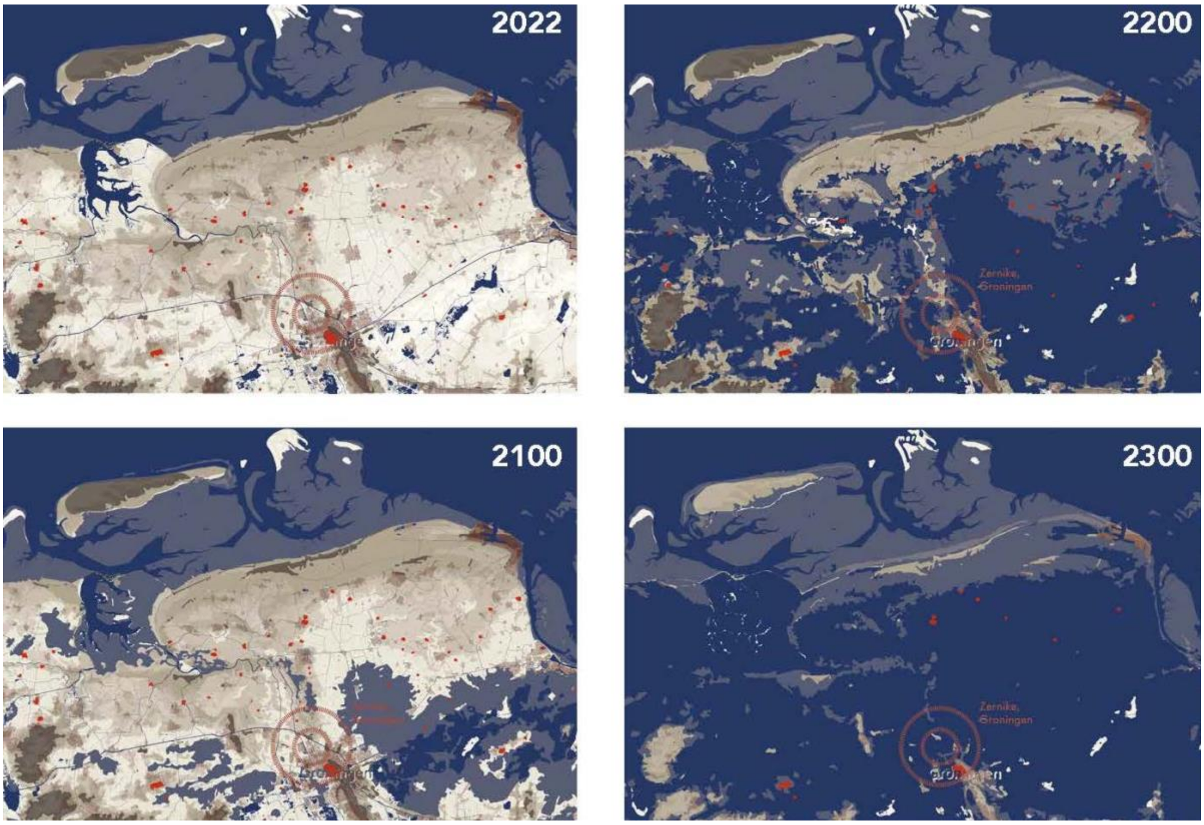

Figure 4. Graphical representation of the impact of sea level rise on the wider region of the case study area.

Table 1. Summary of the three design research projects.

	Design Research Project 1	**Design Research Project 2**	**Design Research Project 3**
name	Autonomous Zernike 2200	The future sea "louch" (*village*)	Grow with trees
Ecosystem Services (mostly emphasized)	provisioning	cultural	regulating and supporting
main challenge	floodings, salinisation, food shortage	floodings, place identity, (student) housing in the campus	floodings, biodiversity, biobased building materials
guiding theme	"wierden" (*mounds*) and abbeys	"wierden" (*mounds*) and local village typology	circularity: a "forest city"

3.3.1 Design project 1 | Autonomous Zernike 2200 – a climate adaptation master plan focusing on food self-sufficiency

In 2100 the food system is expected to increasingly come under the influence of saline conditions (Figure 5). This means traditional agricultural crops, such as potatoes, sugar beet or grassland, will over time be replaced by saline crops such as samphire, sea lavender, sea fennel, arugula and purslane. The current dietary habits are most likely going to change to a saline based diet (Figure 6). Besides the need to harvest and store rainwater, using seawater to meet the increasing demand is explored in this project.

- Step 1— Past equilibrium.
  The study area used to have a rich natural landscape of marshes, ponds and ditches, which was fed by the sea through the Reitdiep river. Past equilibrium analysis indicates that the built environment gradually outweighed the natural ecology in the study area, which resulted in limited cooling and water absorption ecosystem services, and therefore increased the potential flooding risk.
  Historical landscape elements (most of which can no longer be recognized in the existing situation) played an important role in the proposed master plan (Figure 7), for instance the proposed (elevated) path network has been developed based on the historical mobility network of the area (Figure 8), the proposed ditch pattern was based on the past water network, while the proposed mounds are designed in a way that takes into account the pre-existing natural shape of the Reitdiep river.
- Step 2—Worst-case scenario.
  According to the worst case scenario, the study area will be characterized by demographic growth, sea level rise (Figure 5) and food shortage, due to drought and salinisation.

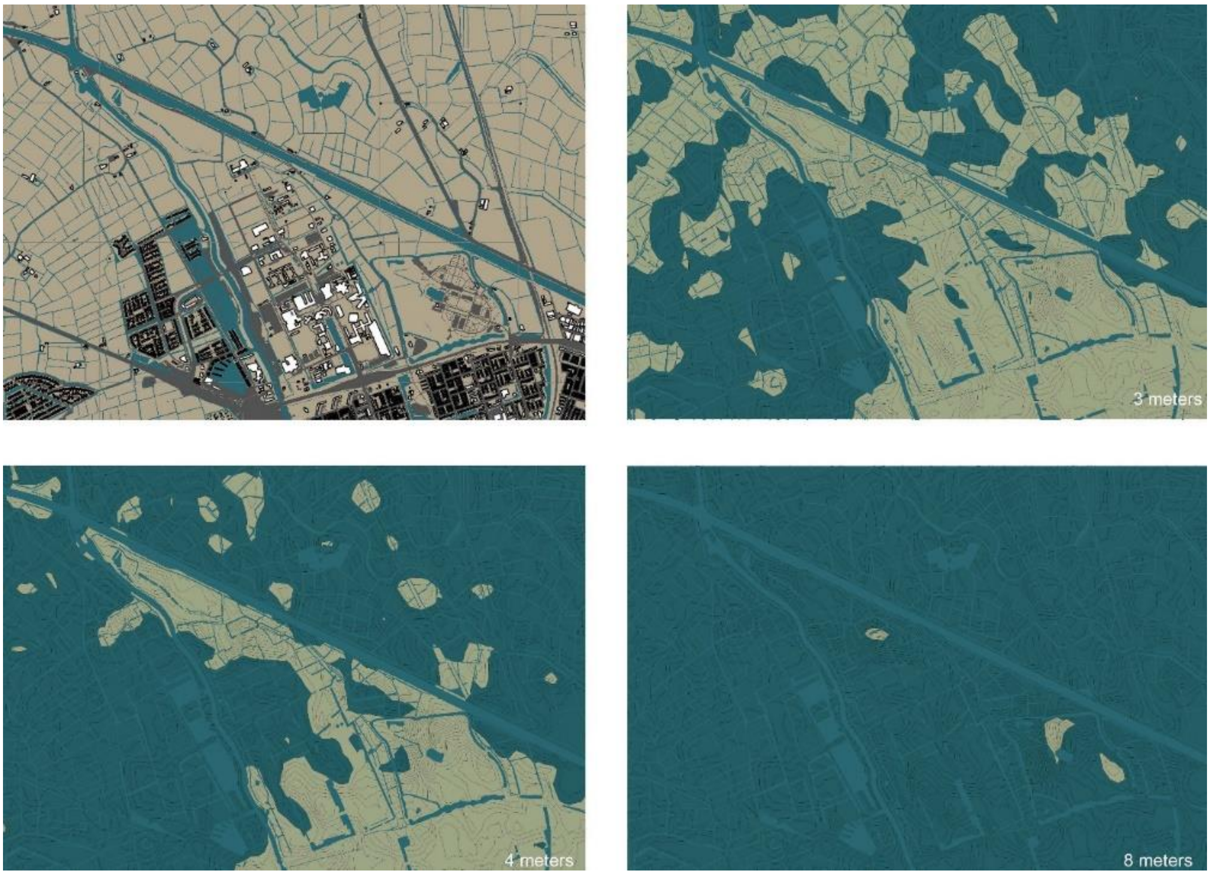

Figure 5. Diagrams depicting the current and future state of the study area with regard to the expected sea level rise (8 meters in 2200).

- Step 3—Safeguarding/enhancing ecosystem services
  Provisioning Ecosystem Services: In this research-by-design project an effort is conducted to convert the threats of sea level rise and salination into opportunities. Specifically, in the case of sea intrusion in the wider region, new agricultural production practices might become possible, such as lobster, shrimp and fish farming, while duckweed ponds and high peat bogs can also emerge (Figure 6).

Figure 6. Diagram depicting the proposed food transition.

Specifically, aquaponics is a method of growing food that combines conventional aquaculture (the cultivation of aquatic animals such as snails, fish and crustaceans) with hydroponics (the cultivation of plants in water) in a symbiotic way. The mangroves are very suitable environments for large population of fish and wildlife. For this reason, it is proposed that fish farms develop near mangroves, contributing to the food supply and local economy of the future Zernike area.

Regulating and Supporting Ecosystem Services: "Wierde" constitutes the guiding theme of this project (Figure 7). A "wierde" is an artificial mound, offering a dry place at high tide, and it is a typical landscape element of the entire coast of the Wadden Zee and the wider region of the Northern Netherlands. These landscape elements historically served the independency of the settlements built on top of them, by offering protection in the case of floodings.

Cultural Ecosystem Services: In the proposed master plan, the case study area consists of a complex of mounds (Figure 8), on top of which housing, education and working activities take place.

- Step 4—Gradual implementation

  The proposed master plan requires a gradual spatial transformation of the study area, aiming at converting it into a resilient, nature-based, self-sufficient, multi-functional residential area. The gradual transition is supposed to take place within both the physical and the mental sphere.

Figure 7. Frame of references: the renaturation of the Swiss river Aire; the Wierde landscape element (in dry and flooding situation).[1]

[1] http://www.landezine.com/index.php/2016/06/renaturation-of-the-river-aire-geneva/; https://www.fietsen123.nl/route/historische-wierdedorpjes-in-groningen; https://www.groningerarchieven.nl/actueel/agenda/69-leven-op-terpen-en-wierden

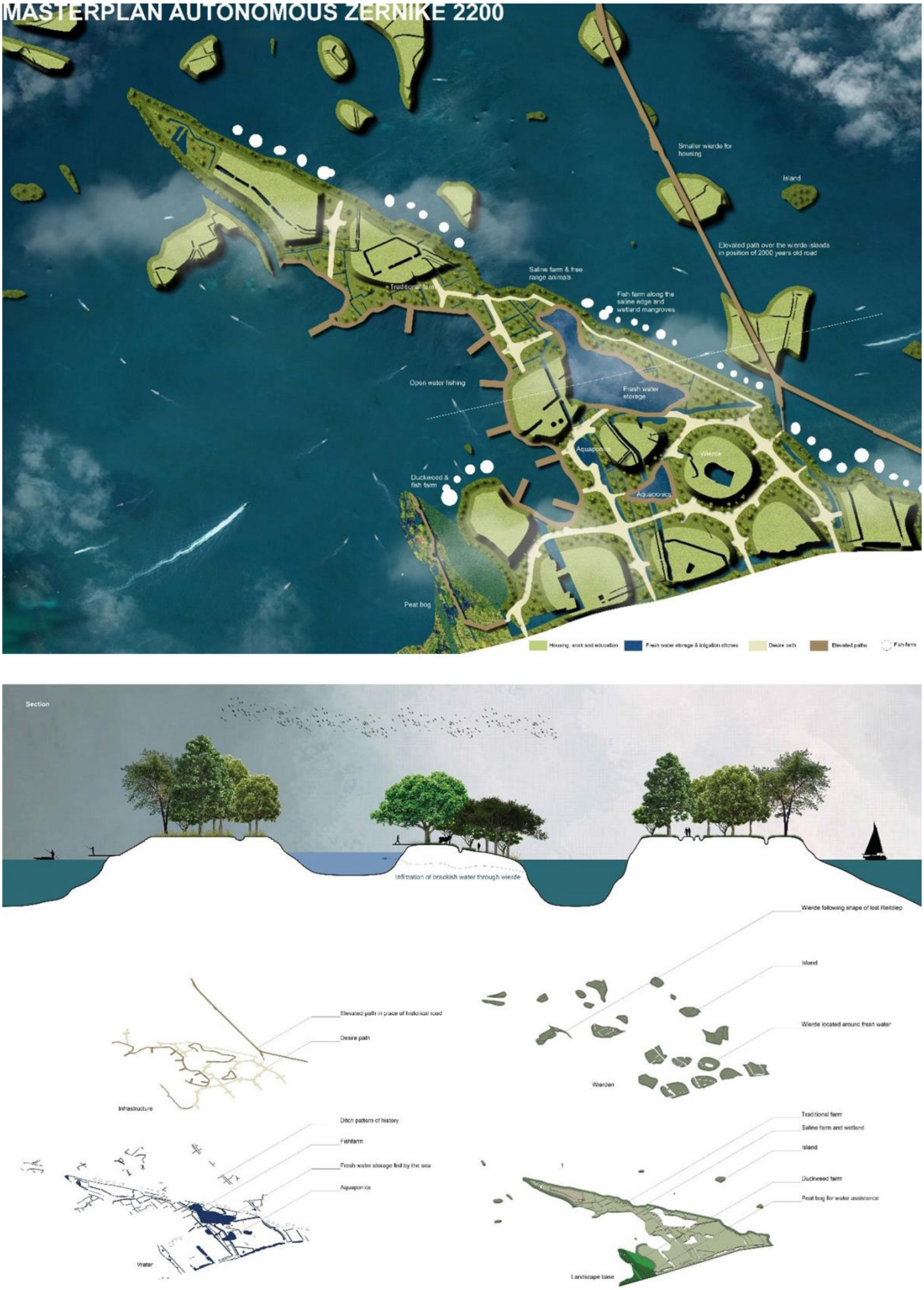

Figure 8. The master plan for 2200, where the key elements of the mounds, the (elevated) path network and the fish farms can be seen.

3.3.2 Design project 2 | The future sea “louch” (*village*) – a climate adaptation master plan focusing on place identity

The lowlands landscape and the character of the rural area of the North of Netherlands constitute the main inspiration sources for this project, which regards the Zernike case study area as an area where the residential tissue of the city of Groningen is going to be expanded. Specifically, according to the scenario of this project, an increasing demand for housing in the biggest cities is expected, due to the sea level rise and the flooding of rural areas. Additionally, the trend of online education is expected to continue, resulting in a reduced need for monofunctional university campuses. Thus, the main goal of this design research project is to propose a master plan for this city extension that takes into account the place identity, a mixed land use approach, as well as climate adaptation considerations.

- Step 1—Past equilibrium

  In the historical analysis of the water system in the case study area, it can be seen that gradually more artificial channels and lakes are introduced in the area (Figure 9). The starting point of this design research proposal is to allow the gradual renaturation of the canal network, to allow the study area become more anti-fragile with respect to future climate change challenges.

Figure 9. Historical analysis of the water system in the case study area.

- Step 2—Worst-case scenario

  Due to sea level will rise, Zernike is expected to become adjacent to the sea in 2100. Additionally, longer summers are expected, resulting in rainstorms turning into monsoons, while the rising temperature is expected to intensify the heat island effect (Figure 10). Finally, biodiversity is expected to decline tremendously.

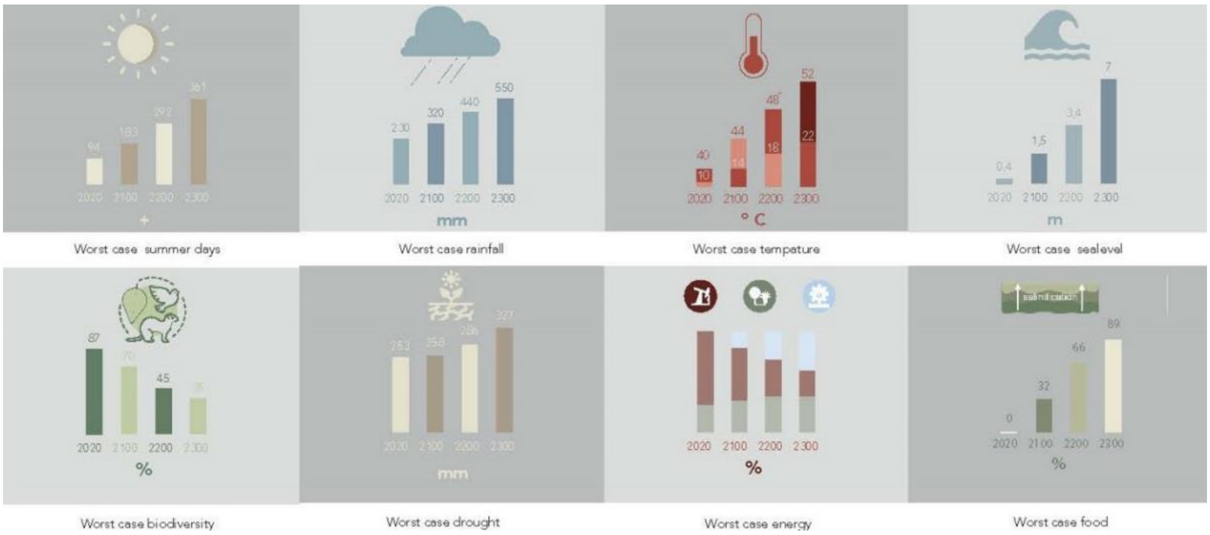

Figure 10. The estimated impact of climate change on the case study area.

- Step 3—Safeguarding/enhancing ecosystem services
  Provisioning Ecosystem Services: The study takes the hypothesis that in 2100 most of the existing buildings will have been recycled (within a material circularity approach), while some of them will be converted into structures facilitating vertical farming. Specifically, farming is proposed to revolve around seaweeds, kale and fish (instead of potatoes and beets). Algae development is also proposed to play an important role in the self-sufficiency of the study area, both in terms of Co2 absorption, as well as in terms of the creation of building material. The waste from this process, but also from (vertical) farming can be transformed in biogas, while the waste water can be purified in a natural helophyte and algae filter (Figure 11).
  Cultural Ecosystem Services: The built environment is organized in mixed land use clusters that are developed on top of a "wierden" (mounds) landscape approach (Figure 12). The local socio-cultural identity of the wider region is also taken into account in the proposed guidelines and indicative representations. Residential, work, retail, education and entertainment are the key functions in these clusters.
  Regulating and Supporting Ecosystem Services: The renaturation of the rivers and streams that (used to) exist in the case study area is proposed, via the development of a grid that provides the potential of reshaping according to the morphological conditions.
- Step 4—Gradual implementation
  The key ideas of the emergence of mounds and of the renaturation of the canal network are supposed to be gradually developed in the case study area, as it can also be seen in Figure 13.

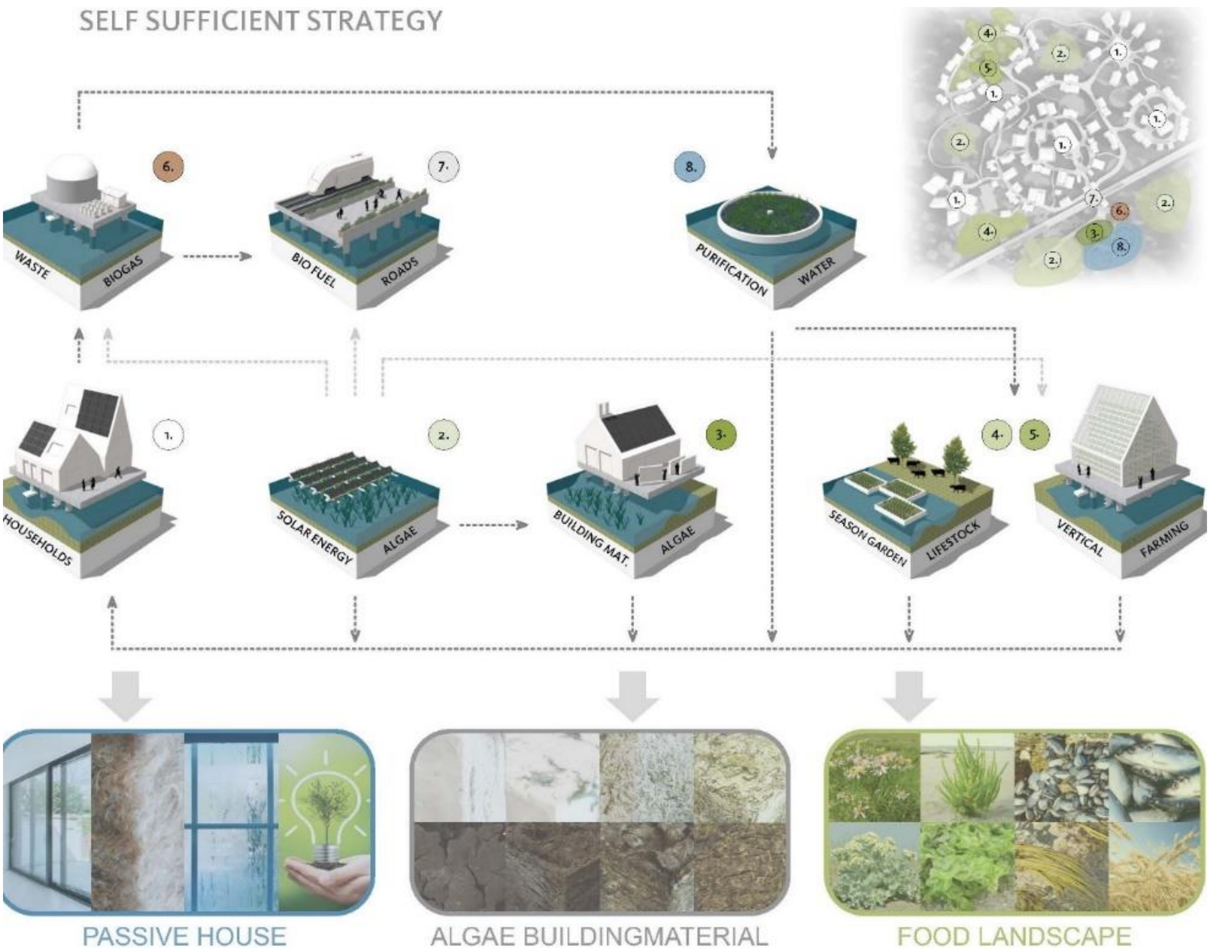

Figure 11. Diagram depicting the self-sufficiency aspects of the proposed master plan.

Figure 12. Photorealistic representation indicating a cluster of built environment developed on a "wierde" (mound).

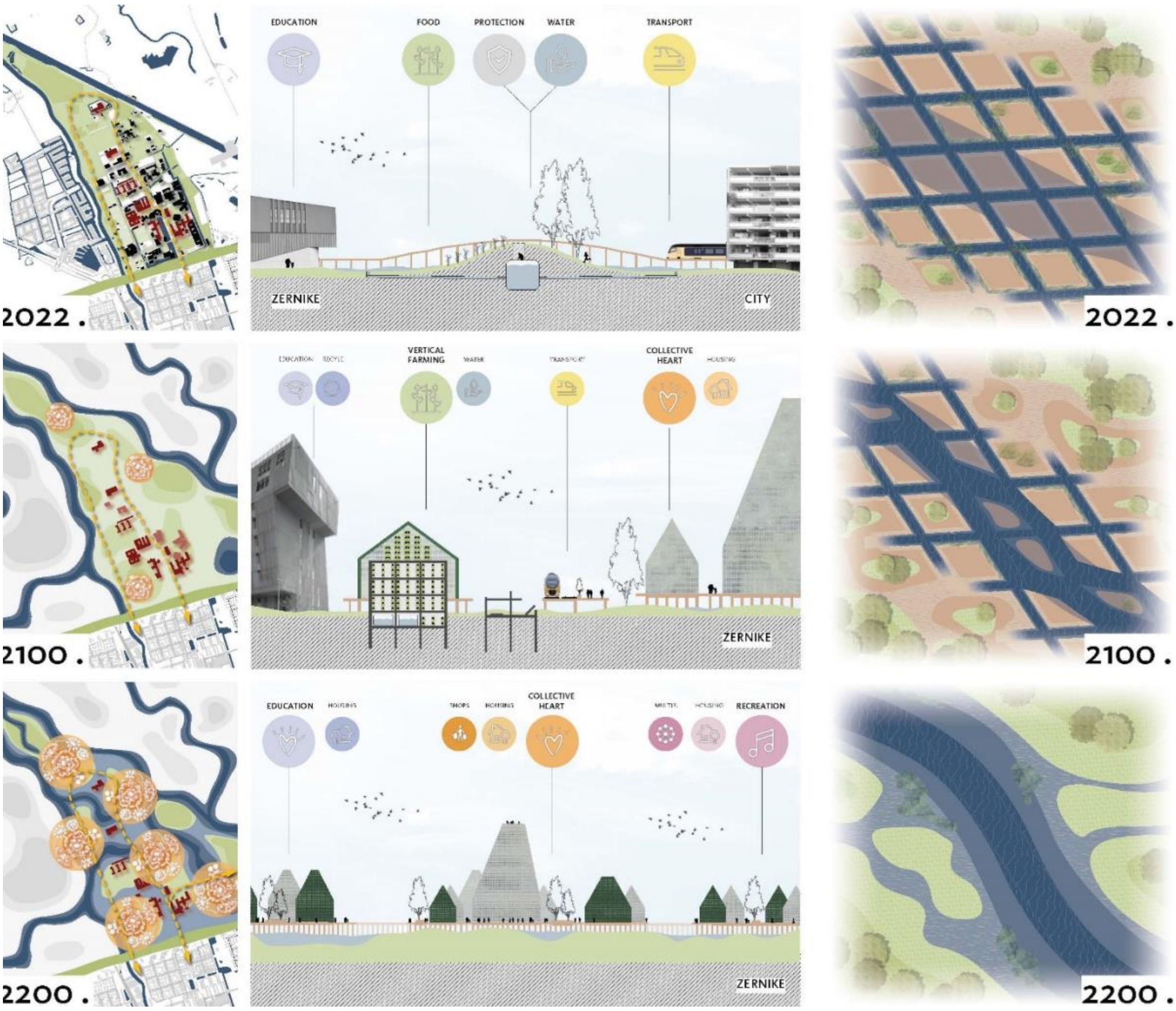

Figure 13. Diagram depicting the short, mid and long-term perspective of the proposed transition strategy.

3.3.3 Design project 3 | Grow with trees – a climate adaptation master plan focusing on circularity

The starting point of this project is on the spatial scale, and specifically it is the concept of the development of a "green ring" surrounding the city of Groningen (Figure 14), with Zernike being an integral part of it. Specifically, a mixed use residential area is proposed to be developed in Zernike, where greenery and contact with nature will play a key role.

Figure 14. Diagram depicting the "green ring" concept for the city of Groningen. The "green ring" can serve as a buffer zone for the excessive rainwater in the case of heavy rainfalls, but also having a cooling effect in Summer. A new railroad track and additional P&R locations are also included in this vision.

- Step 1—Past equilibrium
  In the historical analysis of the case study area, it can be seen that till 1950 the area was exclusively covered by farmland (Figure 15). Then, educational buildings and mobility network infrastructure has been added, gradually outweighing greenery and nature. The starting point of this design research proposal is to allow the gradual conversion of Zernike into an peri urban park, which will be part of a green ring surrounding the city of Groningen and making it more climate adaptive.

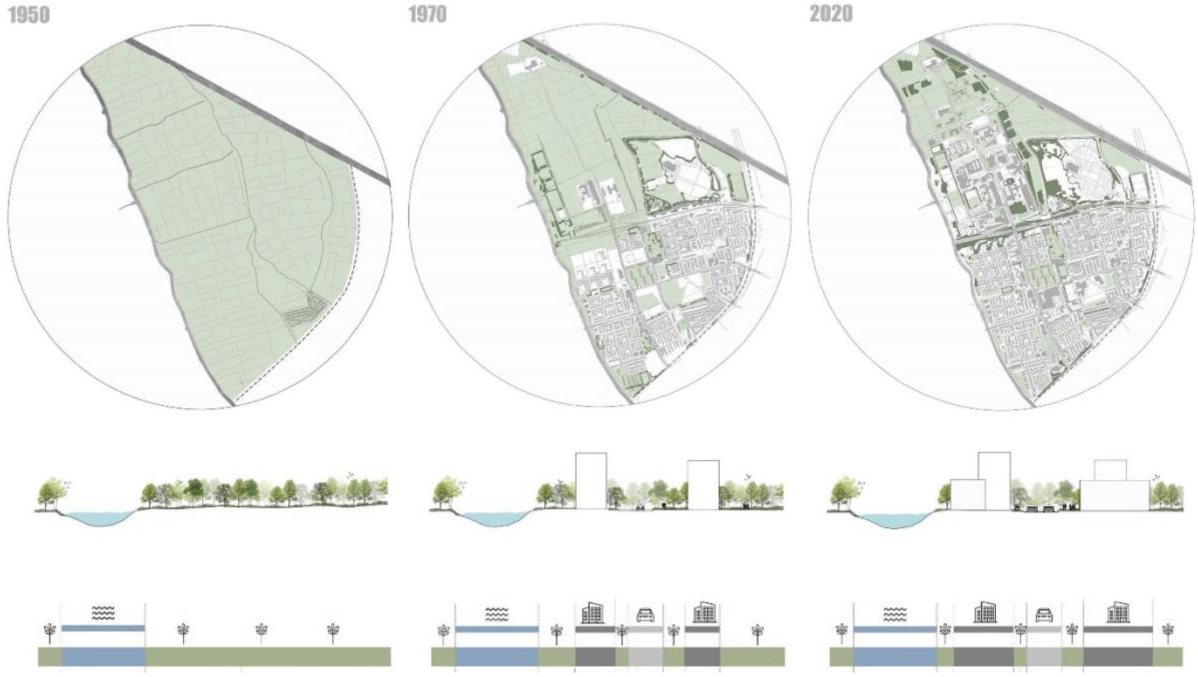

Figure 15. Historical analysis of the ratio between nature and built environment in the case study area.

- Step 2—Worst-case scenario
  According to the climate change scenario of this design research project, in 2100, the rising sea is expected to flood part of Groningen province. This will cause about ninety-one thousand people having to migrate to higher areas, such as the Hondsrug of Groningen. This will cause pressure to the city of Groningen, most probably leading to urban sprawl and increased density.
- Step 3—Safeguarding/enhancing ecosystem services
  Provisioning Ecosystem Services: According to the proposed master plan, timber for manufacturing products and housing will be grown within the case study area (Figure 16). Specifically, green zones are proposed in a direction following the prevailing wind direction, also contributing to the natural cooling of the area. Additionally, the existing built environment is taken into account in the allocation of these green corridors, so that planting can begin within a short-term time horizon. A green zone is also allocated in the west, to protect from the strong wind gusts. Moreover, an industry processing wood to building elements is proposed to be allocated in the plateau in the north. Finally, the existing water

bodies are proposed to become interconnected and broadened, to allow in the long-term, the transportation of the produced building elements.

Cultural Ecosystem Services: Studies have shown that people function better and feel happier when having a view of greenery. Additionally, if an individual spends 120 minutes a week in nature, they are happier and healthier (University of Exeter, 2019).

Regulating and Supporting Ecosystem Services: CO2 storage is achieved with the proposed green zones. In addition, buffer zones where water can be collected are proposed in the west side of Zernike (based on a topographical analysis). Finally, air and noise regulation services are enhanced by the green zones proposed in the study area.

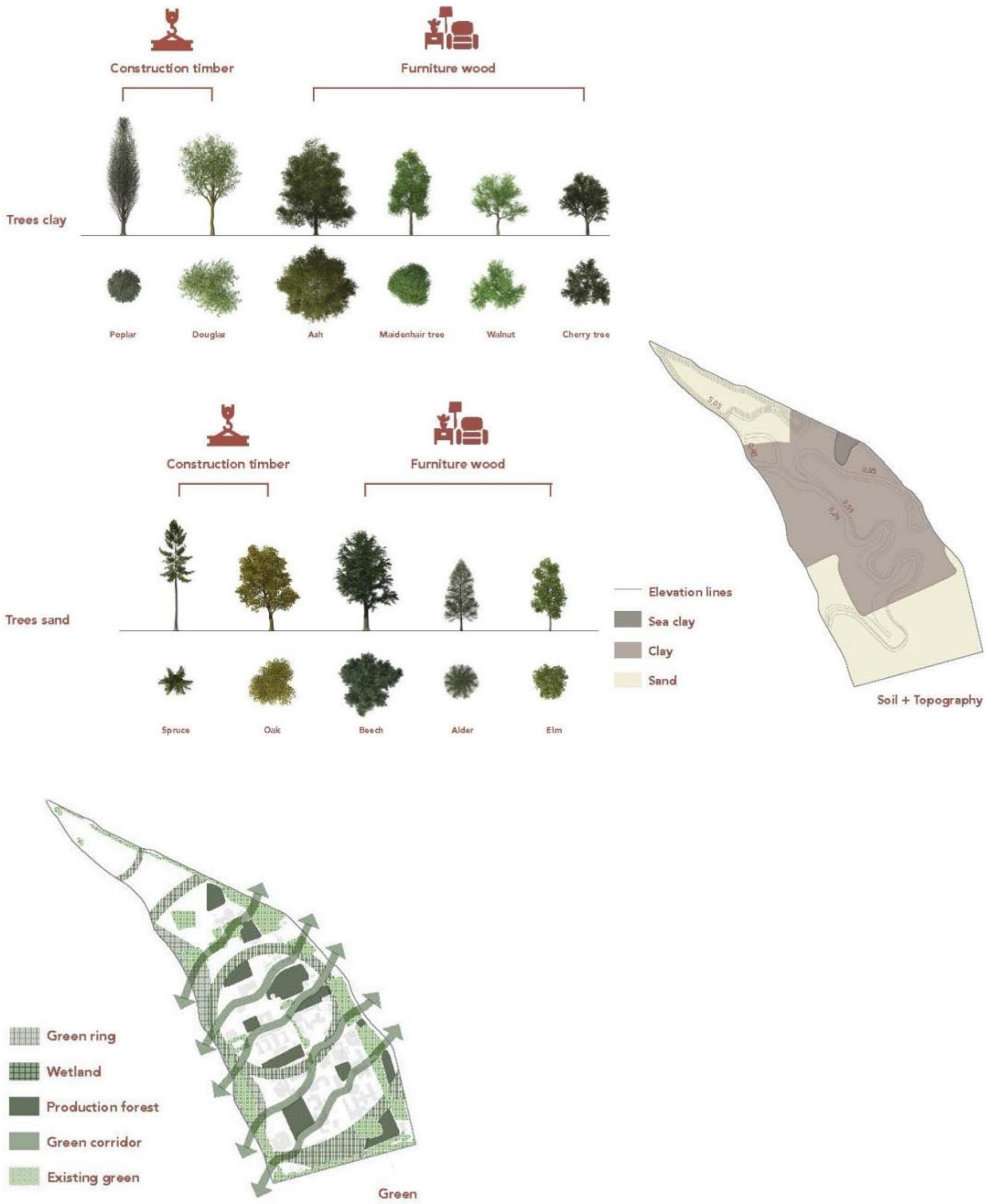

Figure 16. Diagram depicting the suitable types of trees for the type of soil and the desired purpose.

- Step 4—Gradual Implementation
  The proposed plan is a generic solution, characterized by a holistic approach taking into account various layers of the study area (Figure 17), thus incorporating several gradual transition processes.

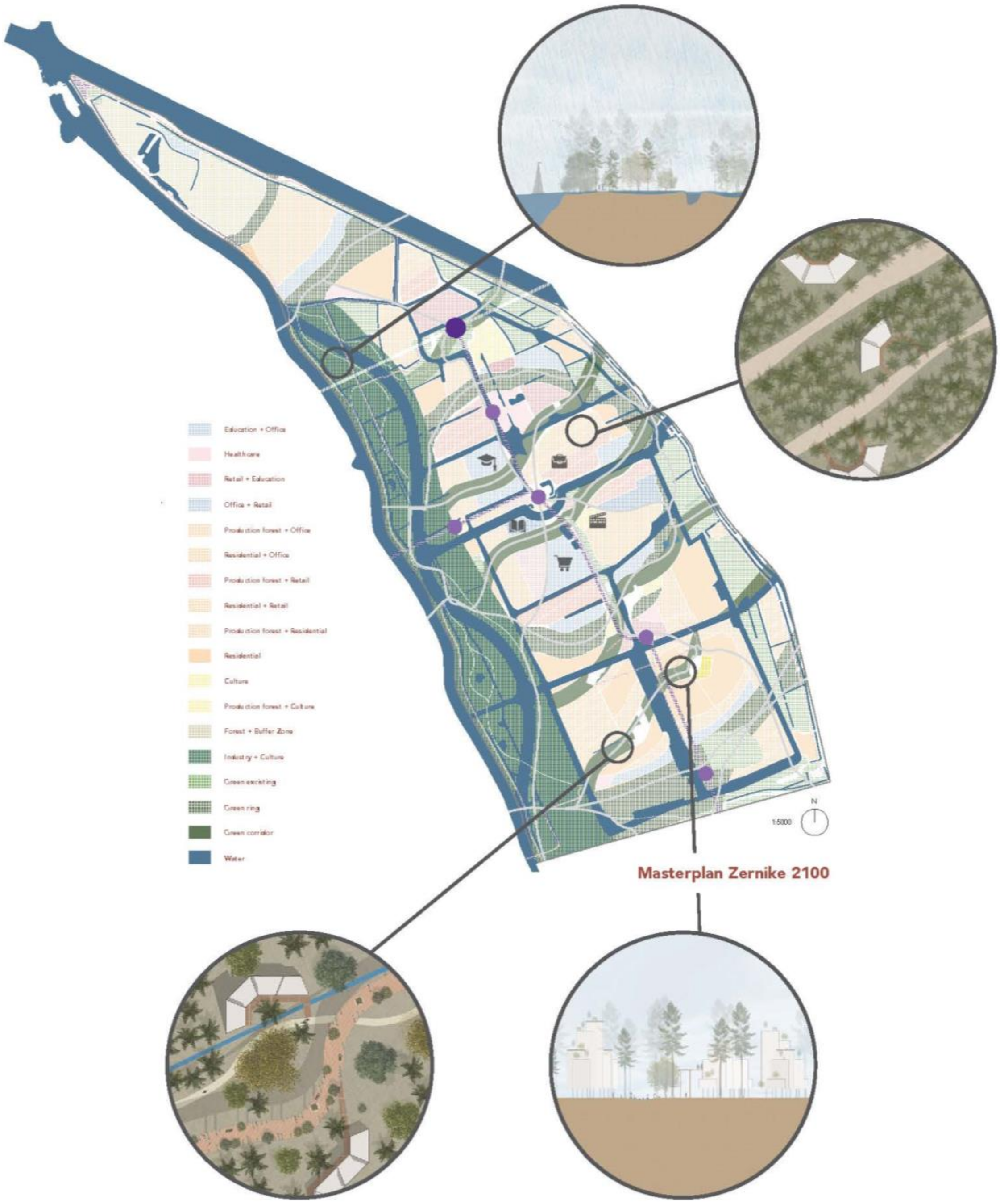

Figure 17. The proposed master plan of this design research project.

3.4 Insights from students' feedback

At the landing process of the design studio, the students have been asked to provide feedback on the impact of the 4-step research-by-design strategy on their process and final outcome. As it can be seen in Figure 18, the students indicated that the findings of the first three steps had an impact on the final design solution, with the worst case scenario having the biggest. This can be explained by the fact that this step triggered them to visualize the impact of climate change on the study area, making the threats more explicit, and the challenge of converting them into (design) opportunities more clear.

Additionally, in the question about the Ecosystem Services and the extent to which they played a role in the proposed solution, most of the students indicated that the regulating ecosystem services have been the most important, with the provisioning, cultural and finally the supporting ecosystem services following (Figure 18). Indicatively, students mentioned in their feedback:

> "*The findings about the worst case scenarios, but also about the present ecosystem services help a lot, because they let you see what needs to change*";

while when describing their proposals they could make explicit various aspects of their design research process, such as:

> "*My major drive was to increase the provisioning ecosystem services, by using the landscape in my design as much as possible*";.

Summing up, the majority of the students when reflecting on the course of this design studio, mainly emphasized the catalytic impact that the third step of the implemented strategy (exploring future scenarios regarding the impact of climate change on the study area) had on their understanding of the case study area:

> "*Boosting existing ES and reacting to the worst case scenario was the backbone of my design process*"; "*The scenario about the maximum flooding due to sea level rise helped me visualize the future landscape of the study area and then react on it with my design*"; "*I consciously tried to see the benefits from the worst case scenario*".

Nevertheless, some students have also emphasized the key importance of exploring previous (equilibrium) states of the case study area on their design research process, as they served as anchoring points for their proposals:

> "*Being aware of the past states and the transformation processes of the study area, gave important starting points for the design process*"; "*I looked at the past equilibrium, which resulted in implementing the past swamp ecosystem that was once there*"; "*the past gave perspective, while the future forced us to look at the long-term*".

Furthermore, it could also be noticed that the method implementation helped the students to investigate and extend their system understanding in a broader context, beyond the strictly defined borders of the case study area. Finally, the majority of the developed projects have been characterized by a gradual, phased sequence of implementation (according to the fourth step of the strategy), with the students generating visualizations explicitly describing the short, mid and long-term phases of the proposed transition solutions (Figure 18).

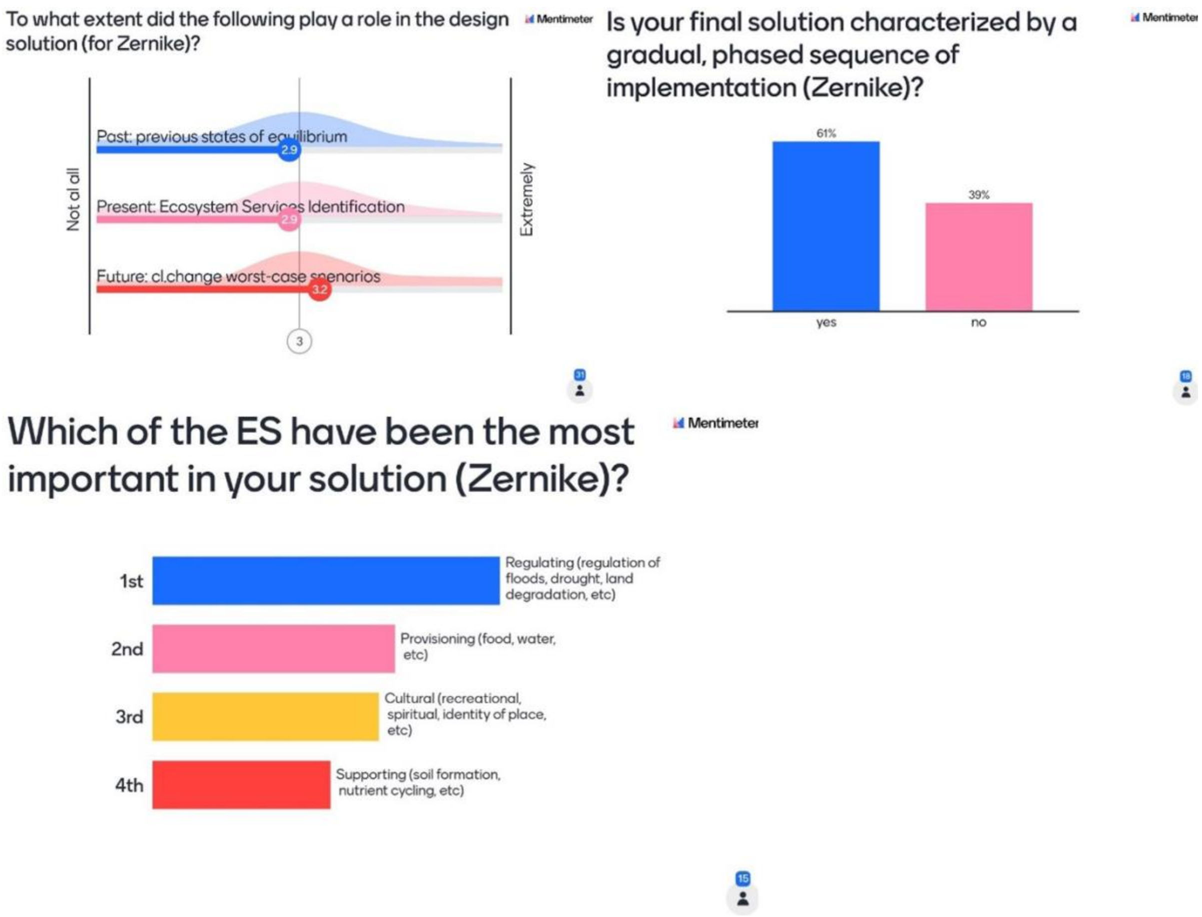

Figure 18. The feedback received by the participating in the design studio students, regarding the impact of various aspects of the 4-step methodology on their design proposal.

4 Discussion and conclusions

4.1 Key findings

The purpose of this study was to test, within a design studio educational setting at a Master of Architecture degree program in the Netherlands , a research-by-design strategy for climate adaptation solutions by using the Zernike university campus in Groningen as a case study. The strategy consisted of four steps, and the primary result of each stage is used as an input for the following step while also being re-examined.

Three design research projects with a particular focus on flooding were selected to illustrate the proposed research-by-design strategy. Interestingly, although all three cases prioritized resilience against frequent flooding, they all approached this design challenge through different perspectives, by, for instance, emphasizing food production, quality of urban life, cultural identity and circularity of building materials.

The starting point of the three design research projects was to approach the study area as a system and analyze its history. The resistance and resilience approaches (Restemayer et al., 2015) that took place in the broader context of the study area were the focus of the first project. The second project investigated the water network system and the way it evolved over time. The third project studied the ratio between nature and built environment, as well as soil conditions.

The second step in all three projects was the formulation of worst-case scenarios regarding the impact of climate change on the study area. As explained above, the three projects focused on extreme weather phenomena and, particularly, on the increased frequency and intensity of heavy rainfall, sea level rise and flooding. Notably, formulating the worst-case flooding scenario for the study area helps to unveil the size of the threat, to realize its spatial implications, and to convert it into an opportunity (by exploring ways of unravelling the transformative potential of the study area).

The identification of the relevant ecosystem services leads to more comprehensive student proposals that take both the physical and the mental sphere of the (broader) study area into account. All three projects explored, by implementing research-by-design, how spatial interventions can create a positive impact on the area. For instance, in the first case, the provisioning services play an important role by introducing a system of food production within a saline context, however in the meanwhile the guiding theme of abbeys is proposed for shaping the surrounding built environment, which is directly related to the cultural services of the area. In the second project, cultural services are prioritized. However, regulation services are also taken into account by clustering the built environment in mounds. Finally, in the third case, regulating services are prioritized, by organizing greenery into buffer zones and by deliberately giving space to excessive water, in case of flooding. However, the transformation of the study area into a peri-urban park, is also set within the broader context of developing a green ring surrounding Groningen, which is expected to also contribute to the social and cultural sphere of the city.

The gradual and flexible implementation process of the designed solution was considered in all three design research projects. Essentially, the implementation process adopts a complex adaptive system approach by embracing uncertainty and leaving space for the unpredictable. In all three projects, the upscaling potential of the proposed design solution was emphasized.

Finally, it is interesting to notice that each of the three design research projects included ideas that eventually attempted to result in lifestyle changes. It was realized by the students, that for the designed solutions to have any real impact, people and communities would need to adapt culturally through occasionally drastic changes in behaviour.

4.2 Implications on design education

Architectural design studios are crucial components of architectural education, providing students with hands-on experience in design thinking, problem-solving, and creative expression. Various learning and teaching approaches are employed in architectural design studios to facilitate the development of students' design skills and understanding of architectural principles. Indicatively, project-based learning, critique and review sessions, design research and analysis, sketching and visual communication, collaborative learning, and integration of technology can be mentioned (van Dooren, et al., 2020; Kolarevic, 2005; Groat&Wang, 2002, Ching, 2010). In the climate adaptation design studio where the four-step research-by-design strategy has been tested, aspects of all these approaches have been combined, since the students had to develop design proposals for a real case study area, and to respond to actual environmental and social challenges that this area faces. The three first steps of the methodology have been conducted collectively, but the design proposal was individual work. Various means of communication and visualization of the analysis findings and of the design proposals have been utilized. Tutoring and (collective) critique sessions have been taking place on a weekly basis. The implementation of the four-step research-by-design strategy gave more structure and a more systematic character within this learning and teaching context.

Specifically, the main contribution of this study are the gained insights by the implementation of a four-step research-by-design strategy on a climate adaptation design studio, which focused on the transformation of a university campus. This strategy helped the students to effectively approach and analyse the study area and formulate innovative climate adaptation design proposals. Students were encouraged to confront uncertainty and avoid design fixation by the process' exploratory nature. Each step of the proposed strategy is followed by a feedback loop, which has been reflected on the learning process of the students: the feedback loops enabled the students to better understand the content they interacted with, resulting in better design outcomes.

In particular, the strategy acted as a roadmap for advances in pedagogical techniques. The strategy undertaken in the design studio also enhanced students' development as researchers by helping them to comprehend contemporary environmental and climate change challenges. Therefore, further studies on research-by-design methodology to investigate different urban or rural contexts across various scales should be encouraged.

The initial testing of this strategy in the research and design studios on climate adaptation, which had taken place in 2020 in the same Master's Degree, resulted in similar findings (Psarra et al., 2021). One of the main differences between the design studios of 2020 and 2022 is that the case study area of the former was the whole region of Lake District, UK, while the latter focused on a much smaller and strictly defined area, which is currently monofunctionally used, as a campus for higher education and (innovation) business. One of the major challenges in the case of the design studio of 2022 was for the students to systematically broaden the scope of their analysis in order to be able to conduct the first three steps of the strategy. An additional challenge was to recognize and identify ecosystem services within an urban context; especially the cultural ecosystem services within a non-residential area. However, the fact that the students had to undergo through the particular steps of the strategy, urged them to think systematically and approach the study area through different perspectives (of time) and across various scales. That is also depicted on the design solutions, as for instance guiding themes stemming from the past equilibrium analysis of the wider region have been used.

Overall, it can be concluded that the proposed strategy helps the researcher designer to embrace uncertainty and to generate gradual long term solutions, to convert the threats of climate change into opportunities and to arrive at radical, but also place-based solutions which take into account both the physical and the mental sphere of the study area.

4.3 Limitations and future research

More practice-based studies are needed to provide concrete examples and hence to discuss the potential of the implemented four-step strategy in climate adaptation design. As discussed, the findings demonstrate context-specific data collected in a particular Master of Architecture degree program. The indicative design interventions are arguably not complete, but do in any case highlight new ways of understanding and intervening in the context of climate change.

Finally, collective learning activities like charrettes and workshops (with the local society and/or other stakeholders) can be implemented into the design process for practice-based implications of research-by-design, and the proposed four-step methodology can be used to give these collaborative efforts more structure. In particular, a collaborative approach including existing and potentially future local residents and other stakeholders, could inform the exercise and take conclusions further, with the design and implementation process also serving as a means to collaborate on mutual behavioural change (of designers, as well as of people and communities).

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