BEYOND ALL LIMITS CONFERENCE 2025

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WATER SUSTAINABILITY

Integrated Water Resource Management
Water-Energy Nexus in Urban Planning
Sustainable Urban Drainage Systems
Water Recycling and Reuse Technologies
Resilient Water Infrastructure Design

MULTI-SCALE APPROACH TO INTEGRATED WATER RESOURCE MANAGEMENT FOR ARCHITECTURAL AND URBAN RESILIENCE IN THE EUROPEAN CONTEXT

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Multi-Scale Approach to Integrated Water Resource Management for Architectural and Urban Resilience in the European Context

Abstract: Climate change is causing increasingly intense and frequent extreme water-related events, making it necessary to adopt architectural and urban measures capable of increasing the resilience of cities. This contribution aims to demonstrate how integrated rainwater management can be implemented through multi-scale approaches, each involving the adoption of recurring architectural strategies. To this purpose, based on the analysis of recurring design practices, a matrix of general objectives, specific objectives and architectural macro-strategies is developed. This matrix is used to analyse a set of representative case studies in the European context, divided into three application scales: district/neighbourhood, site and building. The paper illustrates in detail three projects representative of each application scale, allowing to understand how architectural strategies recur according to the multiscale nature of the intervention.

Keywords: integrated water management; resilient design; multi-scale approach

Introduction

In the light of the global climate crisis, sustainable and conscious water management plays a strategic role in increasing urban resilience to extreme weather events such as flooding and drought. The main water-related issues related to climate change are concentrated in urban areas and can essentially be traced back to two central challenges: the qualitative and quantitative management of large volumes of water generated by increasingly violent and frequent extreme weather events (IPCC, 2023), exacerbated by high soil sealing and outdated sewerage systems (Gawlik et al., 2017); the widespread scarcity of water resources, due to increased demand, overexploitation or poor management (Un-Water, 2024), further amplified by future scenarios of prolonged drought (IPCC, 2023).

These criticalities worsen in climatic regions most vulnerable, like the Mediterranean hotspot, where the increase in extreme precipitation and flash floods (Llasat et al., 2016) is associated with a paradoxical progressive process of drying (Hertig & Tramblay, 2017). These conditions amplify the risks for cities, making it essential to implement measures to adapt to extreme events, while ensuring the conservation and protection of water resources.

Mitigation and adaptation strategies have entered European policies long before the Green Deal, which however set more ambitious targets (European Commission, 2019). With the new European Adaptation Strategy, climate neutrality is supplemented by the goal of climate resilience by 2050, making the drafting of national adaptation plans a formal commitment for Member States (European Commission, 2021). Despite the progress made at European level, climate adaptation is still struggling to be effectively integrated into national action plans: in 2022, 82% of plans focus exclusively on mitigation (Triollet et al., 2022). This highlights the urgent need to promote a systemic and integrated vision of climate resilience. Sustainable water management is of key importance, supported by multi-scale design approaches for the adoption of synergistic strategies tailored to specific local conditions.

Objectives

This contribution aims to demonstrate how sustainable water resource management methods can be incorporated into design practices at multiple scales, highlighting how each application scale involves specific recurring architectural strategies. The analysis and synthesis of design experiences reveal three macro-strategies for integrated water resource management:

- source control, consisting of measures to prevent and reduce water runoff and potential pollution, limit consumption and improve local environmental quality;

- water diversion, which involves conveying water to water bodies, downstream Sustainable urban Drainage Systems (SuDS) or public sewers, providing benefits in terms of speed and flow reduction and potential integration of purification functions;

- water reception, consisting of accommodating water inside or close to flood-proof structures designed to contain it, reducing flood risks.

In order to understand how the three macro-strategies recur in relation to the multiscale nature of the intervention, a matrix of priority objectives and specific sub-objectives related to the three architectural strategies is developed. Each of the three priority objectives is divided into 12 specific sub-objectives, which can be implemented through one or more architectural macro-strategies (Fig. 1). This matrix is applied to analyse a set of case studies selected from the international scene, particularly in Europe, as examples of best practice in sustainable and integrated urban stormwater management. Each project is contextualised climatically and classified according to three scales of application: district/neighbourhood, site (including open spaces on a plot such as squares or courtyards) or building.

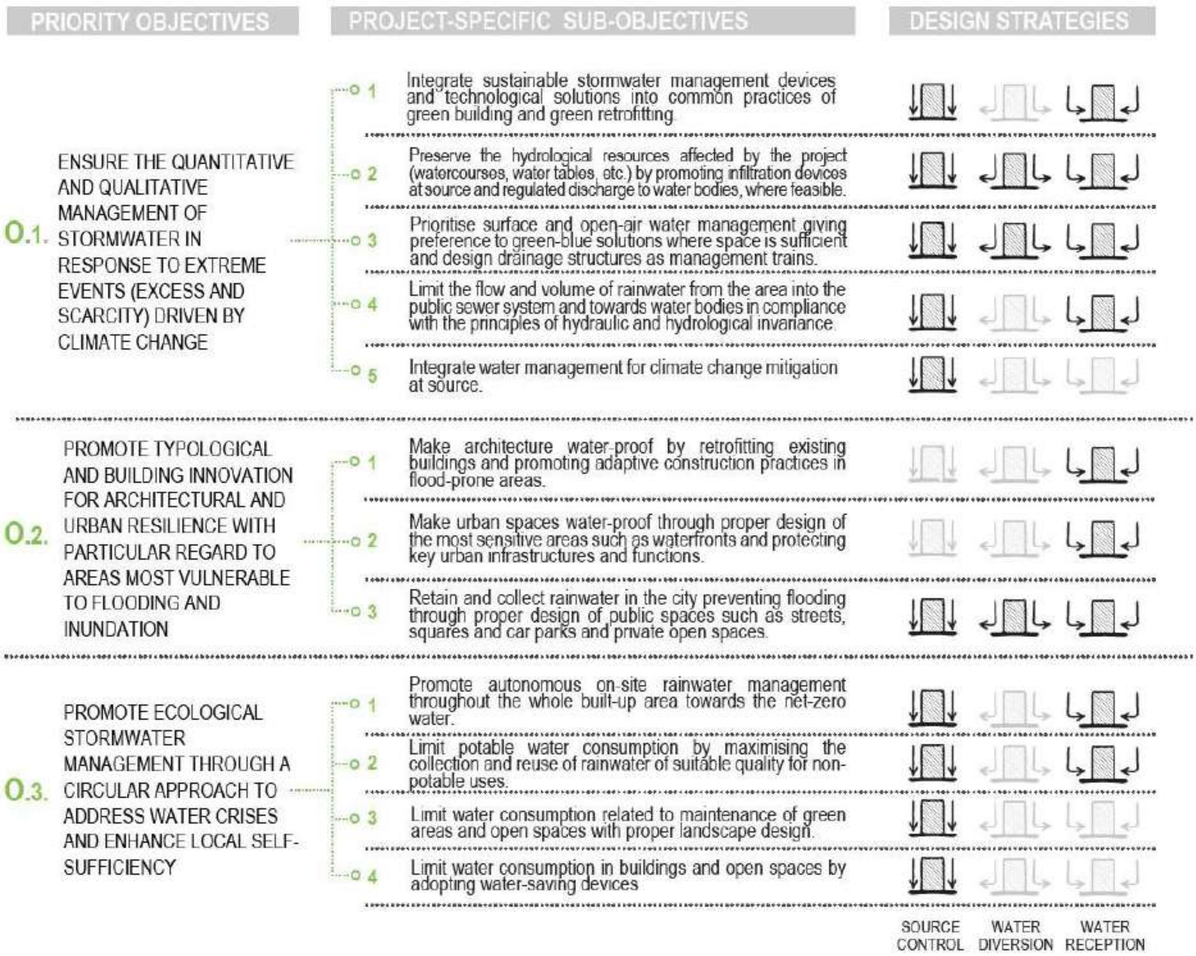

Figure 1. Matrix of priority objectives, project-specific sub-objectives and design strategies for integrated rainwater management (© the Authors [LMG]).

The paper illustrates the methodological process of case studies selection and describes in detail three representative projects for each application scale. The analysis and comparison of the three case studies allows for critical considerations on architectural strategies related to project objectives and application scales.

Methodological process of case studies selection

Starting from an initial list of 50 global case studies, chosen for their effectiveness in innovative and sustainable urban stormwater management, the selection is based on two main criteria: scale and technological component. Urban and regional scale projects and high-tech projects difficult to apply in ordinary contexts are excluded. From the remaining 37 projects, similar ones or those lacking adequate documentation are eliminated, resulting in a final selection of 17 case studies, all located in Europe and completed or nearing completion (Fig. 2). These projects provide replicable examples in ex-temperate climates such as the

Mediterranean hotspot, focusing on regeneration in consolidated urban areas predominantly residential, mostly completed, tested and monitored over time.

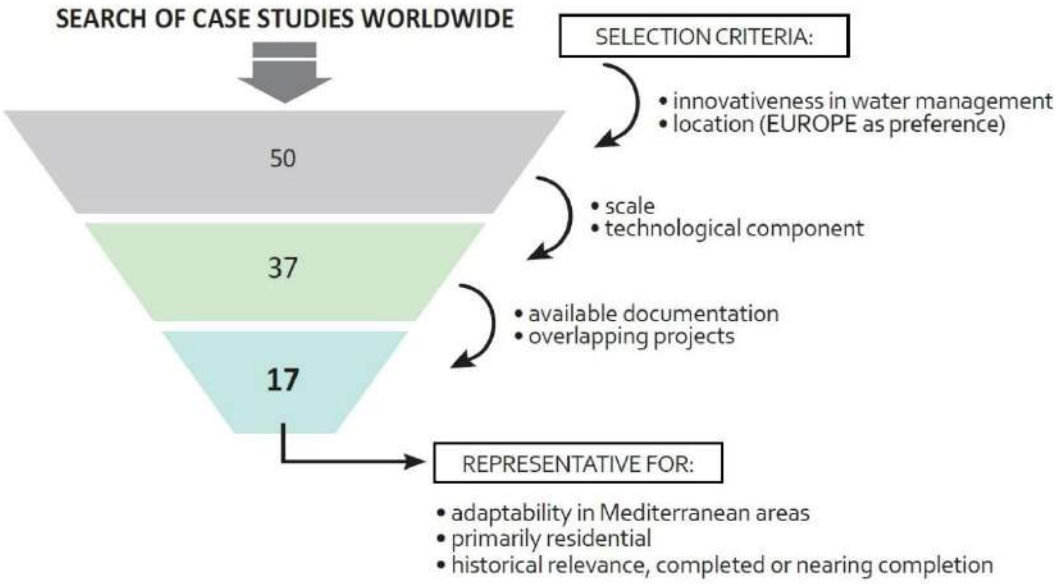

Figure 2. Case studies selection process and criteria used to identify the 17 representative projects (© the Authors [LMG]).

The decision to focus on Europe, already included in the initial selection phase, aligns with EU regulatory and policy framework, providing replicable design strategies towards the 2050 climate resilience European goal.

Among the 17 case studies, three projects with different typological characteristics are selected, representative of the three different application scales:

(1) Ekostaden Augustenbor, Malmö, Sweden (district/neighbourhood);

(2) Clarenhof, Mechelen, Belgium (site);

(3) Nuremberg Prisma, Nuremberg, Germany (building).

Case studies analysis

The three selected case studies (Fig. 3) provide a multi-scale overview of the architectural strategies that can be applied within the design process for integrated and sustainable stormwater management (Fig. 4).

Figure 3. The three case studies analysed. From left: Ekostaden Augustenbor (© Jorchr, via Wikimedia Commons); Clarenhof (© Enidanc, via Flickr); Nuremberg Prisma (© Aarp65, via Wikimedia Commons).

The Augustenborg neighbourhood in Malmö has faced decades of flooding due to an outdated combined sewer system. Heavy rains damaged basements, garages and infrastructure, and untreated sewage overflowed into waterways due to overwhelmed treatment plants.

Climate projections indicate winter rainfall may rise by 50 mm by 2080, worsening flood risks.

The Ekostaden Augustenborg project, launched in the 1990s, introduces a new paradigm of sustainable urban drainage based on three principles: infiltration, detention and slow transport. The solutions implemented include over 6 km of open channels and ditches, 10 retention ponds and 30 green roofs, covering a total of 2,100 m². The 9,500 m² Botanical Roof Garden is the largest in Scandinavia and features extensive and intensive green roofs, including experimental ones. Green roofs retain about 50% of annual rainfall, reducing peak flows and contributing to an overall reduction in runoff of 20% through evapotranspiration (Kazmierczak & Carter, 2010).

The stormwater management system is divided into three sections, each with different design approaches (Månsson et al., 2021). In the southern area, the first to be built, the system follows a strongly architectural design inspired by the 1950s consisting of visible gutters, concrete channels and ornamental ponds. The system is designed to handle events with a 25year return period. In the northern area, a more naturalistic approach is adopted, involving swales, vegetated ponds and hidden gullies connected directly to the gutters. The system is sized for ten-year rainfall events, with a greener and less formal aesthetic. Finally, along Augustenborgsgatan, a separate system is built consisting of a conventional underground pipe, made necessary for topographical reasons. This diverts rainwater directly to the urban canals, relieving pressure on the main sewer network.

Thanks to its integrated system, Ekostaden Augustemborg now handles 90% of rainwater from impervious surfaces locally using open-air solutions, almost completely relieving the combined sewer system, which carries nearly exclusively wastewater. The system has proven to be remarkably effective over time: since its completion, there have been no further floods, even during the exceptional rainfall event of 2007, classified as a fifty-year rainfall, which severely affected other parts of the city (Kazmierczak & Carter, 2010). In addition to hydraulic improvements, the project has brought environmental, social and aesthetic benefits, increasing biodiversity and creating enjoyable public spaces, making Augustenborg one of the finest examples of urban resilience to date.

The Clarenhof project redevelops a decayed parking block in the centre of Mechelen into a multifunctional complex of 64 apartments, 32 dwellings, two commercial units, and underground parking (WIT architecten, n.d.). Built around a semi-public water garden, it is characterised by the reopening of the historic “Vliet” watercourse, a key infrastructure for sustainable rainwater management.

Within the courtyard, public and private paths define topography and space. The surfaces vary in permeability, gradually becoming more permeable and vegetated as they approach the Vliet. Rainwater is collected via channels and overflow systems and conveyed into the watercourse, while the private gardens promote infiltration and aquifer recharge.

The project uses three main water management systems: rainwater reuse, buffering, and water-saving measures (Dudek, 2012). Each home is equipped with a 3,000-litre cistern that collects rainwater from the roofs; this is connected to a unit that allows the water to be reused for toilets, washing machines, irrigation and car washing. In drought conditions, an integrated buffer volume is filled with drinking water to ensure continuity of use. In the apartments, reuse is limited to shared areas (i.e. garden irrigation, taps in the car park and supply for commercial activities). Buffering occurs via the cisterns of individual homes, which overflows into the city drainage system, and through the Vliet, which receives the excess water from the collective cisterns of the apartments and the green areas, including green roofs, and overflows in the separate city rainwater-sewer. Green roofs also act partly as buffers, retaining and slowing down runoff. Water-saving measures include: dual-flush toilets (6-9 litres for solid waste, 3-4.5 litres for liquids) that allow an average saving of 40,000 litres of water per family per year; lowflow shower heads and aerators reducing water and energy by 40%; hot water recirculation systems to minimise waste; thermostatic taps and efficient mixers that optimise water flow and temperature.

The sustainable management system adopted significantly reduces the pressure on the sewerage network, preserves water resources and improves environmental quality.

Figure 4. Multi-scale stormwater management in the case studies analysed. From left: Ekostaden Augustenbor (Mottaghi et al., 2021); Clarenhof (Dudek, 2012); Nuremberg Prisma (Corfone, 2012).

Located in the centre of Nuremberg, the Prisma project consists of two buildings arranged at an angle on a completely sealed 6,000 m² site. The buildings have mixed functions: commercial spaces on the ground floor, offices on the middle floors and duplex apartments on the upper floors. A glass greenhouse connects the blocks above underground parking. The project is built to passive house standards, ensuring high energy efficiency (sdg21, 2016).

The project focuses on completely on-site rainwater management. All rainwater collected from roofs and tanks on the fifth-floor flows into a 240 m³ underground cistern, after being filtered through purification biotopes (Hoyer et al., 2011). From here, the water feeds two circuits: one irrigates the tropical plants in the greenhouse and a 100-metre watercourse; the other activates a natural air conditioning system consisting of five coloured glass water walls. In summer, falling water draws hot air down, cooling the environment; in winter, the same water – kept at 18°C – preheats incoming air (Dreiseitl & Grau, 2009). Before installation, simulations assessed the effectiveness of the natural air conditioning, with results later confirmed in practice. In summer, plants and water walls reduce the internal temperature by up to 3°C. Night ventilation and greenhouse openings double airflow, further lowering the internal temperature (sdg21, 2016).

Collected rainwater is reused for multiple purposes: in addition to irrigation and natural air conditioning, it supplies fire-fighting systems and a series of open-air elements – such as indoor and outdoor pools, water walls and water features – which contribute to the spatial and sensory quality of the environment. Surplus water is stored in a 50 m³ gravel layer below the parking. Here, thanks to the permeability of the sandy soil and the depth of the water table, water can naturally infiltrate the subsoil (sdg21, 2016).

Fully independent from the public sewer network, the system improves evaporation, infiltration, temperature, and humidity. Designed to handle ten-year return period rainfalls, Nuremberg Prisma adapts to even to more intense rainfalls, thanks to its multiple integrated components that are still efficient and well maintained today (Hoyer et al., 2011).

Discussion and conclusions

The three case studies, critically analysed and compared via the matrix developed, show how source control, water diversion and water reception strategies can be applied in a synergistic and multi-scale approach (Tab. 1).

Table 1. Presence of the three architectural strategies in the case studies analysed referring to their application scales.

	District/ neighbourhood	*Site*	*Building*
	Augustenborg, Malmö, Sweden	**Clarenhof, Mechelen, Belgium**	**Nuremberg Prisma, Nuremberg, Germany**
S1. Source control	○	●	●
S2. Water diversion	●	○	-
S3. Water reception	○	-	-

Notes. (●) identifies the main strategy; (○) identifies any complementary strategies; (-) means that the strategy is not implemented

At the end of the process, project-specific summary sheets have been developed. Each sheet is divided into two main sections: the first section classifies projects by scale of application and summarises key information, including geographical location and project details; the second section analyses the case studies according to the reference matrix, specifying the project inputs, the main objectives pursued, and the strategies adopted. Where multiple strategies are present, the main strategy is identified, followed by one or both complementary strategies.

It is interesting to note that, based on the project objectives, the three macro-strategies act synergistically the greater the scale of intervention. This depends directly on the higher spatial articulation and on the technical features of the solutions adopted. In Augustenborg (Fig. 5), water diversion emerges as the driving strategy: a dense network of swales and open drains conveys water away from critical areas, mitigating peak flows. At a complementary level, source control is provided by permeable surfaces, while water reception occurs in basins and floodable areas. This synergy makes the neighbourhood a pioneer in high resilience standards. The Clarenhof complex (Fig. 6) integrates widespread on-site measures for soil unsealing, rainwater recovery and water saving, with source control as its main strategy, supported by water diversion, resulting in controlled transport toward and through the Vilet itself, reconnecting to the public network. Finally, in the Nuremberg Prisma (Fig. 7), water follows a virtuous cycle of collection, filtration, reuse and infiltration, all integrated into the building scale. Source control is the only feasible strategy and makes the building a highly efficient ecosystem that is totally independent in stormwater management from the public network.

The constant presence of source control shows that effective management must begin at the source, integrating permeable surfaces and on-site reuse. Water diversion and water reception strategies are more viable at site and neighbourhood scale and, when combined with the former, act as a "management train" where multiple sequential interventions work together to enhance stormwater resilience.

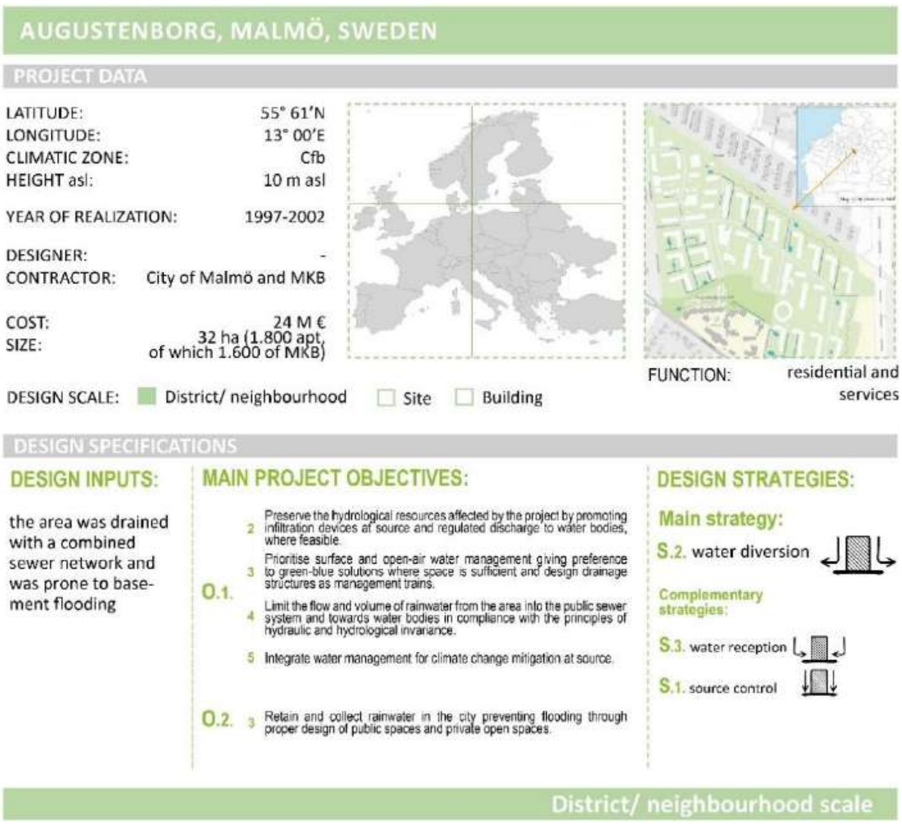

Figure 5. Summary sheet: Ekostaden Augustenbor (© the Authors [LMG]). Localization plan extract from (Mottaghi et al., 2021)

Figure 6. Summary sheet: Clarenhof (© the Authors [LMG]). Typological plan from (Dudek, 2012)

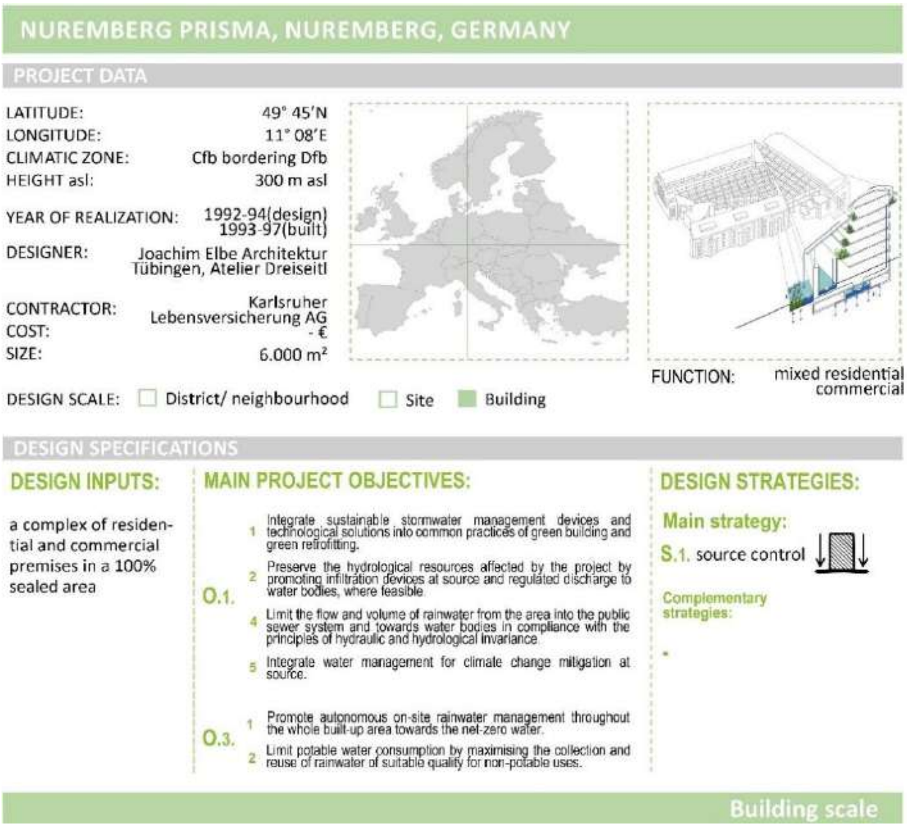

Figure 7. Summary sheet: Nuremberg Prisma (© the Authors [LMG]). Axonometric section from (Corfone, 2012)

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