

Multidimensional System Approach to High-Rise Buildings in Urban Areas as Integral-Active Ecosystems

A Case Study in Hanoi, Vietnam

Dissertation

For the degree of Doctor of Engineering (Dr.-Ing.)
at the Faculty of Spatial Planning
TU Dortmund University

submitted by

Tobias Michael Kuester-Campioni

Dortmund, 28.01.2026

Author Tobias Michael Kuester-Campioni
Dipl.-Ing. Architektur
Born at 23.08.1976 in Brühl (Rheinland)
Email: tkuester76@gmail.com

Reviewers Prof. Dr. rer. nat. habil. Nguyen Xuan Thinh
TU Dortmund University
Department of Spatial Planning
Research Group of Spatial Information
Management and Modeling (RIM)

Prof. Dr. Dietwald Gruehn
TU Dortmund University
Department of Spatial Planning
Research Group Landscape Ecology and
Landscape Planning (LLP)

Chairman of the Examination Committee
Prof. Dr. Frank Othengrafen
TU Dortmund University
Department of Spatial Planning
Research Group Urban and Regional
Planning (SRP)

Day of the oral examination 25. February 2026

© 2026 Tobias Kuester-Campioni (ORCID iD: [0000-0001-8385-8376](https://orcid.org/0000-0001-8385-8376))

The electronic version of this dissertation is available at:

<https://eldorado.tu-dortmund.de>

Acknowledgements

This dissertation was completed during my tenure as a research associate for the Smart-Urban-Areas (SUA) research project at the Research Group of Spatial Information Management and Modeling (RIM) under the supervision of Prof. Dr. Nguyen Xuan Thinh. This collaborative research endeavor between TU Dortmund University, WILO SE, and the local partner Vinhomes was funded by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) from September 1, 2022, to December 31, 2025.

During this period, I had the privilege of interacting with numerous individuals who consistently encouraged me in the realization of this work. Therefore, special gratitude is extended to the closest colleagues at the research group and within the SUA project.

First and foremost, I would like to express my gratitude to Prof. Dr. Nguyen Xuân Thinh for his formal guidance, Prof. Dr. Dietwald Gruehn for his technical and scientific support and Prof. Dr. Frank Othengrafen for the overall perspective. Within the RIM team I send special thanks to Dr. Mathias Schaefer, Anna Dumke, Haniyeh Salari, Sinan Karakus, Flemming Eismann and Pham Nhat Anh for their project contribution and friendship. Furthermore, I thank Gero Boehmer from WILO SE for his active collaboration in achieving the project goals; the team from Abionik, with particular recognition to Carola Dannen for their technical support on site, as well as the Vinhomes team, including Bui Lan Anh and Quynh Anh for on site coordination. Finally the Z-U-G team, Julia Buccini, Grit Kallmeier, and Daniel Roos, for handling the challenging project within the funding period. Special thanks are going to Sophie Girlich from TU Berlin as Master student who supported the project with her economical insights.

In Vietnam I want to extend my profound gratitude to the Truong Chi Trung family for their contribution of their building as TestBed 2 for research purposes, Nguyen Ngoc Thang from GreenTec for his all-time support and friendship, Dr. Nguyen Việt Hoai from the Research Center for Environmental Monitoring and Modeling (CEMM) for contributing TestBed 1, Mr. Nguyen Trung as relevant networker, Mr. Long for its IT input, Prof. Dr. Nguyen Dang Minh for contributing TestBed 6 and Douglas Snyder from the Vietnam Green Building Council (VGBC) for his cooperative partnership .

Finally, deep appreciation is expressed to my family and friends in Germany and Vietnam. Extraordinary thanks are owed to my sons, Moritz and Emil, and my wife, Christiane, who have accompanied me through all the highs and lows of the past years and have been an essential pillar of support in my life. The dedication belongs to my parents and parents in law.

Abstract

The proliferation of new urban and smart areas has become a dominant development strategy in the Global South, including Vietnam, where rapidly expanding residential districts intensify urban density, strain infrastructure, and contribute to urban-heat-island formation. This dissertation proposes an alternative paradigm: to conceptualise cities, districts, and particularly high-rise buildings as multidimensional, metabolically active organisms rather than static, resource-consuming constructions.

Building on this premise, the research employs a multidimensional systems approach to examine the distributive high-rise as an interactive node within a complex urban mega-system. High-rise buildings are investigated not as isolated architectural objects but as adaptive, biophilic, and technologically mediated systems capable of managing and redistributing resource flows - energy, water, and data - while contributing actively to district-level resilience.

The study integrates principles from construction material ecology, green infrastructure, decentralised water management, and digital monitoring. Particular emphasis is placed on the ecological performance of vegetated building envelopes, the potential of decentralised water treatment, and the role of digital shadows and sensor networks in enabling localised feedback loops. These dimensions are explored through a mixed-methods case study of high-rise development in the metropolitan region of Hanoi, where controlled experimental conditions (TestBed 02) and real-scale observations (Tonkin 2) allowed for cross-scalar evaluation across nano-, micro-, and meso-urban levels.

The findings demonstrate that environmental performance in tropical high-rise districts emerges not from singular technologies but from the interaction of ecological, material, and digital subsystems functioning as interdependent metabolic units. Vegetation proved to deliver the most stable long-term performance, while decentralised water systems and sensor infrastructures require substantial adaptation to operate robustly under tropical conditions. The study synthesises these insights into the conceptual model of Adaptive Node Urbanism, positioning high-rise buildings as active contributors to urban resilience rather than passive consumers of resources. Ultimately, this dissertation advances future-oriented planning approaches by illustrating how distributive high-rises and adaptive urban nodes can strengthen local resource cycles, mitigate climatic stresses, and foster more sustainable, resilient, and liveable metropolitan environments.

Zusammenfassung

Die zunehmende Entwicklung neuer urbaner Gebiete prägt die Stadtentwicklung im

Globalen Süden, insbesondere in Vietnam, und führt zu verdichteten Stadtstrukturen, infrastrukturellen Belastungen und städtischen Wärmeinseln. Diese Dissertation schlägt ein alternatives Paradigma vor: Hochhäuser, Quartiere und städtische Systeme als multidimensionale, metabolisch aktive Organismen zu begreifen.

Auf dieser Grundlage untersucht die Arbeit das Konzept des distributiven Hochhauses als adaptiven urbanen Netzwerkpunkt, der Energie-, Wasser- und Datenströme nicht nur effizient verwaltet, sondern aktiv in das Quartier zurückführt. Der multidimensionale Ansatz kombiniert Materialökologie des Hochbaus, horizontale und vertikale Begrünungsprinzipien, dezentrale Wasseraufbereitung und digitale Modelle. Die empirische Grundlage bilden zwei Fallstudien in Hanoi - kontrollierte Messungen (TestBed 02) und Skalierungen (Tonkin 2) - die eine Bewertung über Nano-, Mikro- und Mesoebenen hinweg ermöglichen.

Die Ergebnisse zeigen, dass Leistungsfähigkeit und Resilienz tropischer Hochhausquartiere aus dem Zusammenspiel ökologischer, materieller und digitaler Subsysteme entstehen. Die Vegetation erwies sich als die mit Abstand stabilste Infrastrukturkomponente, während dezentrale Wasser- und Sensorsysteme hohe Anpassungsanforderungen aufweisen und weiterführende Optimierungspotentiale offerieren. Die Studie entwickelt daraus das Konzept des Adaptive Node Urbanism, das Hochhäuser als aktive Bausteine urbaner Resilienz positioniert.

Die Arbeit leistet damit einen Beitrag zu zukunftsorientierten Planungsansätzen für nachhaltige, klimaangepasste und lebenswerte Metropolregionen.

Table of Contents

Acknowledgements	i
Abstract	ii
Table of Contents	iv
I List of Figures	vi
II List of Tables	ix
III List of Abbreviations	xi
1 Introduction	1
1.1 Why buildings and urban areas must be understood as integral organisms? .1	
1.2 Structure of the Dissertation	3
2 Framework and State of Research	5
2.1 The Context of Hanoi and New Urban Areas.....	5
2.2 Urban Areas (UAs) versus Smart Urban Areas.....	7
2.3 System Solutions and Networks.....	9
2.4 The High-Rise Building as an Adaptive Node.....	13
2.5 Modern Urban Network Approach (MUNA)	16
2.6 Research Objectives and Key Question.....	20
3 Project Context and Case Studies	24
3.1 Research Project Smart Urban Areas	24
3.1.1 Academic Leadership	25
3.1.2 Industry Partner	25
3.1.3 Local Partner.....	26
3.2 Case Studies Overview	26
3.2.1 Case Study 1: Tonkin 2	28
3.2.2 Case Study 2: TestBed 1	31
3.2.3 Case Study 3: TestBed 2	32
3.3 Tasks, Timeline and Operational Management.....	36
3.4 Challenges and Limitations.....	39
4 Methodologies and Implementation	43
4.1 Methodologies Overview	43
4.2 Thermographic Imaging.....	45
4.2.1 Preconditions.....	45
4.2.2 Thermal Imaging Camera	46
4.2.3 Thermal Imaging to Building Surfaces.....	47
4.3 Empirical Building Envelope Parameters	49
4.3.1 Building Organism	49
4.3.2 Wall to Window Ratio.....	50

4.3.3 Brick to Concrete Ratio	52
4.3.4 Brick Wall Conditions.....	53
4.3.5 Construction Framework	57
4.3.6 Virtual Modeling as Instrument	60
4.4 Field Study of Green System and Sensor Network	62
4.4.1 Planting Concept and Spatial Organisation.....	62
4.4.2 Miyawaki Method as Greening System	65
4.4.3 Irrigation System.....	66
4.4.4 Maintenance Measures and Protective Structures.....	67
4.4.5 Sensor Network and Visual Monitoring	69
4.4.6 Economics of the Greening System	71
4.5 Field Study Water Infrastructure	72
4.5.1 On-Site Conditions	72
4.5.2 Waste Water Treatment Plant (WWTP).....	73
4.5.3 Installation Process and Monitoring	80
5 Results and Discussion	82
5.1 Thermographic Imaging - Results and Reflections.....	82
5.2 Building Envelope Parameters - Results and Reflections.....	97
5.3 Vegetation Placement and Sensors - Results and Reflections.....	116
5.4 Water Infrastructure - Results and Reflections	129
5.5 Participation	141
6 Findings, Vision and Outlook.....	145
6.1 Summary the Objectives.....	145
6.1.1 Key Findings of Building Envelope	146
6.1.2 Key Findings of Vegetation System	148
6.1.3 Key Findings of Cycles and Loads	149
6.1.4 Key Findings of Digital Interfaces	151
6.1.5 Key Findings of Cross-Site Reflections	152
6.2 Towards a Vision	153
6.3 Contribution, Limitation and Outlook.....	159
References	162
Appendices	171
Declaration of Authorship.....	248

I List of Figures

Figure 1.1: (a) Mixed-use Quartier Hai Phong, (b) Mixed-use High-Rise, new CBD Hanoi.....	3
Figure 2.1: Networks by RAND (illustration based on RAND)	10
Figure 2.2: (a) Cedric Price, (b) Yona Friedman, (c) Archigram.....	11
Figure 2.3: High-Rise. Adaptive Node.....	14
Figure 2.4: Mixed-Use Development (MUD), (a) CapitaSpring, (b) Marina One, (c) Southbank, (d) KL Gateway, (e) Azabudai Hills (based on Project related Sources).....	17
Figure 2.5: Transit Oriented Development (TOD), (a) Dukuh Atas, (b) Shibuya Central (c) Eight Eight, (d) Hudson Yard, (e) Euralille (based on Project related Sources).....	18
Figure 2.6: Methodology of the High-Rise as an Adaptive Node.....	22
Figure 3.1: Research Project Structure	26
Figure 3.2: Case Study Locations within the Urbanity of Hanoi.....	27
Figure 3.3: (a) Tonkin 2 and 1, (b) Site Plan of the VSC 2023.....	29
Figure 3.4: (a) TB1 North Elevation, (b) Location in Yen Lang Area.....	32
Figure 3.5: (a) TestBed 2 North Elevation, (b) Location in Hai Ba Trung District	33
Figure 3.6: (a) Merlin Project Gantt, (b)+(c) Project Management Solution in Communication (schematic View of Simplification).....	37
Figure 3.7: Task Flow within three Years of Project.....	38
Figure 3.8: 3D Data Space within the Case Studies	41
Figure 4.1: Project Scope of Scale.....	44
Figure 4.2: (a) Window Frame from Inside, (b) Sheet Metal Roof grey, (c) Roof Top after Greening, (d) Roof Top before Greening, (e) Detail of Plants and Construction, (f) Surface Temperature of West Wall to East Neighbour	48
Figure 4.3: Building Organism System	50
Figure 4.4: Tonkin 2, Wall-to-Window Ratio (WWR)	51
Figure 4.5: Tonkin 2, Brick-to-Concrete Ratio (BCR)	53
Figure 4.6: (a) Concrete-Brick Wall, (b) Wall-Slab/Beam Transition, (c) AAC Walls.....	55
Figure 4.7: Augmented Reality (AR) and Virtual Reality (VR) Visualisation Process	61
Figure 4.8: Configuration of the Plant Containers A + B	63
Figure 4.9: Irrigation System applied at TestBed 2	67
Figure 4.10: Sensor Placement on TB2.....	71
Figure 4.11: Water Cycle within TB2	74
Figure 4.12: (a) Rul - Flow Diagram (simplified, Standard), (b) Rul Modification Arrangement on Site, (c) Electric Adjustment from EU to VN, (d) Digital	

Meter and five/core Socket Solution, (e) Smart Pump for Irrigation System before Implementation.....	76
Figure 5.1: Thermal Imaging of AC Outdoor Units at Tonkin 2. (a) Twin Unit, (b) Top Surface Heat, (c) Top Outlets of AC Units	93
Figure 5.2: Colour Perception and Thermal Performance through different Lenses: (a) Colour Wheel, (b) Thermal Camera View, (c) Feng Shui Wheel, (d) Thermal Performance	96
Figure 5.3: Schematic Wall Masonry Elevation in Transition to reinforced Concrete Slab / Beam (a) traditional Brick (as built), (b) AAC Block, (c) Poroton Brick Block; and exterior Wall Sections (d) single Layer Brick 150 mm (as built), (e) double Layer Brick 240 mm (required by Regulation), (f) AAC Wall 200 mm and (g) Poroton Brick Block 365 mm.....	99
Figure 5.4: (a) Brick Masonry - Transition to Beam, (b) DL Brick cut, Air Gab visible, (c) DL Brick broken, (d) Thickness Plaster Layer, (e) Brick Deviation and (f) AAC Wall Type	102
Figure 5.5: (a) Tonkin 2 Floor Plan with Concrete Spacers, (b) Zoom Concrete Spacer, (c) Slab Section before and after using Concrete Spacers.....	106
Figure 5.6: (a) Load Comparison A380 on T2, (b) As-built Technical Equipment Arrangement, (c) Cold Water Tank, (e) Chillers, (e) Areas for Wall mounted AC Outdoor Unit/Split.....	111
Figure 5.7: (a) Bird Nesting at TB2, (b) Ant Settlement in the Palm Leaf Sheath, (c) Caterpillar on Bamboo Bracing	117
Figure 5.8: Plant Rehabilitation at TB1 and TB2	118
Figure 5.9: (a) Palm Roots from A and B Container TB1, (b) Close up to Palm Roots in Container, (c) Separation hanging Plants and Rooting.....	119
Figure 5.10: (a) Ring-Drip Irrigation at TB1, (b) Mist-Drip Irrigation for Container A and B at TB2, (c) Drip Irrigation for Container C at TB2	121
Figure 5.11: Deface in Node Casing and on Equipment after ten Months since Commissioning. (a) Discolouration on Wire, (b) Discolouration on Metal Post, (c) ruptured Battery Bottom, (d) in Battery Holder, (e) in Case, (f) ruptured Battery Heads, (g) Deface in Case, (h) Discolouration on Equipment (rel. Humidity / amb. Temperature Sensor).....	124
Figure 5.12: (a) Lip filled with Water, (b) Lip filled with Soil, (c) Sheath after Removal, (d) Coexistence System.....	127
Figure 5.12: Waste Water Pipe Arrangement in the Basement of TestBed 2 with its related Ball Valves.....	131
Figure 5.12: Filtrate Examples for Water Quality Certificates, 16.06.2025. (a) both Samples in 2 Liter Canisters, (b) Sample of Filtrate, (c) Sample of Tab Water.....	137

Figure 6.1: Linear Metabolism	154
Figure 6.2: Circular and Regenerative Metabolism	155
Figure 6.3: Adaptive Node Metabolism	156
Figure 6.4: Distributive Transformation.....	157
Figure 6.5: Distributive Transformation within Megacities.....	158

II List of Tables

Table 2.1: Developments in Hanoi carried out between 2000 - 2024	6
Table 2.2: Classification of current Urban Areas	7
Table 3.1: Occupation and Consumption per capita T2.....	30
Table 3.2: Occupation and Consumption per capita TB2	34
Table 4.1: Tonkin 2, Wall-to-Window Ratio (WWR).....	52
Table 4.2: Tonkin 2, Brick-to-Concrete Ratio (BCR).....	54
Table 4.3: Tonkin 2, exterior Brick-to-Wall Condition (BWC) (as built) of one Square Meter.....	55
Table 4.4: Tonkin 2 Construction Framework Elements	58
Table 4.5: Plants and Replacement.....	68
Table 5.1: Surface Temperatures of West-Facing Facades, Date 07.08.2024, 15:00-16:00.....	83
Table 5.2: Comparative Surface Temperatures of Building Materials measured	85
Table 5.3: U-value Evaluation for one Square Meter	86
Table 5.4: In-wall Temperatures of vegetated and non-vegetated Facades, Date 10.08.2024	88
Table 5.5: In-wall Temperature of vegetated and non-vegetated Facades, Date 10.11.2024	89
Table 5.6: In-wall Temperatures of vegetated and non-vegetated Facades, Date 10.02.2025	90
Table 5.7: Top-Surface Temperatures of Metal and Terracotta	91
Table 5.8: Comparative Wall Material Parameters (per m ² of Wall Area).....	100
Table 5.9: Scaled Parameters on T2 related to BCR (9.796 m ²).....	103
Table 5.10: Scaled Parameters on VSC High-Rise Buildings.....	103
Table 5.11: T2 Comparison to VSC Resource Benefits.....	105
Table 5.12: Concrete Slab Resource Potentials for T2.....	108
Table 5.13: Concrete Slab Resource Potentials for VSC.....	109
Table 5.14: Ball Valve Settings and Results	132
Table 5.15: Water Consumption and Cost (Benefits)	135
Table 5.16: Water Quality Differences of Tap Water, Filtrate and Regulation	138
Table A3.1: Comparative Wall Material Parameters for one Square Meter	181
Table A3.2: Cost Estimations for Materials, Construction Time, CO ₂ Emissions on one Square Meter	184
Table A3.2: Scaled Building Envelope Materials on T2 BCR (9.796 m ²)	186

Table A3.3: Scaled Building Envelope adapted on VSC Hanoi.....	188
Table A3.4: Reinforced Concrete Slab Calculations T2.....	189
Tab. A3.5: Reinforced Concrete Consumption and Potentials at VSC	192
Tab. A3.6: Technical Building Equipment	193

III List of Abbreviations

AAC	Autoclaved Aerated Concrete
AR	Augmented Reality
BCR	Brick to Concrete Ratio
BEM	Building Energy Model
BIM	Building Information Modeling
BWC	Brick Wall Conditions
CBD	Central Business District
CF	Construction Framework
DT	Digital Twin
DS	Digital Shadow
EM	Effective Microorganism
GIS	Geo-Information-System
GFA	Gross Floor Area
gMUD	Green Mixed-Use-Development
gTOD	Green Transit-Oriented-Development
HAU	Hanoi Architecture University
HDPE	High Density Polyethylene
IBC	Intermediate Bulk Container
IoT	Internet of Things
ICT	Internet Communication Technology
LoRaWAN	Long Range Wide Area Network
MUD	Mixed-Use-Development
MUNA	Modern Urban Network Approach
MWC	Masonry Wall Conditions
N	Neutral
PE	Ground Conductor
POD	Pedestrian-Oriented-Development
PP	Polypropylen
SCM	Smart City Movement
SUA	Smart Urban Area
SME	Small and Medium-sized Enterprises
SRI	Sensor Reflecting Index
T2	Tonkin 2
TB1	TestBed 01
TB2	TestBed 02
TM	Twinmotion

TUDO	TU Dortmund University
TOD	Transit-Oriented-Development
UA	Urban Area
UE	Unreal Engine
UHI	Urban Heat Island
VGBC	Vietnam Green Building Council
VM	Virtual Modeling
VR	Virtual Reality
VSC	Vinhomes Smart City Hanoi
WWR	Wall to Window Ratio
WWTP	Waste Water Treatment Plant
ZUG	Zukunft-Umwelt-Gesellschaft

1 Introduction

Chapter 1 provides an overview of the motivation and contextual background that form the basis of the dissertation. The chapter concludes with an outline of the dissertation's overall structure.

1.1 Why buildings and urban areas must be understood as integral organisms?

Over a past period of 25 years, the city of Hanoi has undergone a time of rapid urbanisation and exceptional population growth. According to the *UN World Urbanisation Prospects 2018*¹, the population of the Hanoi Metropolitan Area increased from approximately 1.6 million in 2000 to estimated 6.4 million in 2024, with an average annual growth rate of 3.41% - a trend projected to continue well into the coming decades. At the national level, Vietnam's population rose from 96.5 million in 2019 to over 100.7 million by 2024, reflecting both natural population increase and intensified rural-to-urban migration.

Based on observations as academic assistant made between 2001 and 2003, followed by continuous professional and academic engagement from 2014 to 2025, highlight the intensity and pace of this urban transformation. During this time, Hanoi evolved from a largely provincial capital into an internationally networked metropolis, marked by the expansion of its skyline and the consolidation of large-scale infrastructure systems.

One of the most visible manifestations of this change is the transformation of urban mobility. While Hanoi's streets were once dominated by bicycles, motorcycles, and public buses in the early 2000s, today's streetscape is increasingly characterised by large private vehicles—including SUVs, electric motorbikes, and light commercial vans. According to projections by the Hanoi Department of Transport, the number of registered cars was expected to reach 1.9 million, and motorcycles 7.5 million by 2030 (Vu Van Hien, 2017). This trend toward motorisation is directly associated with rising air pollution, reduced walkability, and negative impacts on public health and urban livability (Pham et al., 2020).

In parallel, Hanoi has witnessed the emergence of extensive high-rise urban developments. These are especially concentrated along strategic transport corridors, such as the new Central Business District at the intersection of Kim Ma and Nguyen Chi Thanh streets, the inner ring road (Vo Chi Cong to Minh Khai), and the outer ring corridor (Phan Van Dong to Do Muoi). Over the last two decades, more than 30 New

¹ https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2018_wup_report.pdf (22.10.2024)

Urban Areas (NUAs) and countless high-rise complexes have transformed the city's morphology, extending into perimeter urban zones and redefining local microclimates, socio-spatial patterns, and land-use logic (Nguyen & Harms, 2019; Hong & Kim, 2023). However, many of these developments are characterised by standardised architectural typologies and limited contextual responsiveness. They often lack connection to public transport infrastructure, ignore climatic orientation, and contribute little to socio-functional diversity. Since the mid-1990s, urban development discourse has been shaped by the Smart City paradigm, generally advocating the use of digital technologies to increase urban efficiency and sustainability. Nevertheless, early conceptualisations of Smart Cities - particularly those associated with "Urban Mega-Systems" - emphasised not only ICT infrastructures but also the integration of natural, social, and built systems in large-scale adaptive feedback loops, but also questioning their inclusivity and accessibility (Hall et al., 2000; Batty et al., 2012).

Recent critiques from within the Vietnamese urban context have problematised the technological determinism embedded in dominant Smart City strategies. Scholars have called for more inclusive and context-sensitive frameworks that account for cultural, environmental, and infrastructural disparities (Thai et al., 2021). This becomes even more pressing in the transition from fossil-based to post-fossil societies, where resilience, equity, and regenerative capacities must be prioritised across urban systems (Bai et al., 2016; Leach et al., 2012).

This study is informed by two interrelated strands of experience. The first is rooted in over a decade of academic lecturing at the Hanoi University of Architecture (HAU), focusing on sustainable high-rise design and the integration of green building materials within dense urban built environments. The second draws from 15 years of professional practice in a global background, including the development of urban quarter concepts and the operation of a multidisciplinary design office in Hanoi operating in the years 2014 to 2020.

Two conceptual design studies conducted in 2018 and 2019 (Figure 1.1) constituted a turning point, signalling the transition from practice-oriented engagement toward a more systemic academic inquiry. Both projects are related to strategies in accordance for existing or establishing CBD developments. One project, located in the historic center of Hai Phong, proposed a multifunctional Mixed-Use Development (MUD) with early elements of Transit-Oriented Design (TOD). The other explored a vertical mixed-use tower within the emerging CBD in Hanoi at Lieu Giai street, including a green rooftop for the residential community. In both cases, systemic questions emerged regarding the role of vertical structure impacts of that size in shaping environmental performance, infrastructural demands, and direct impact of urban quality of life in their surrounding neighbourhoods. These experiences form the ground for this

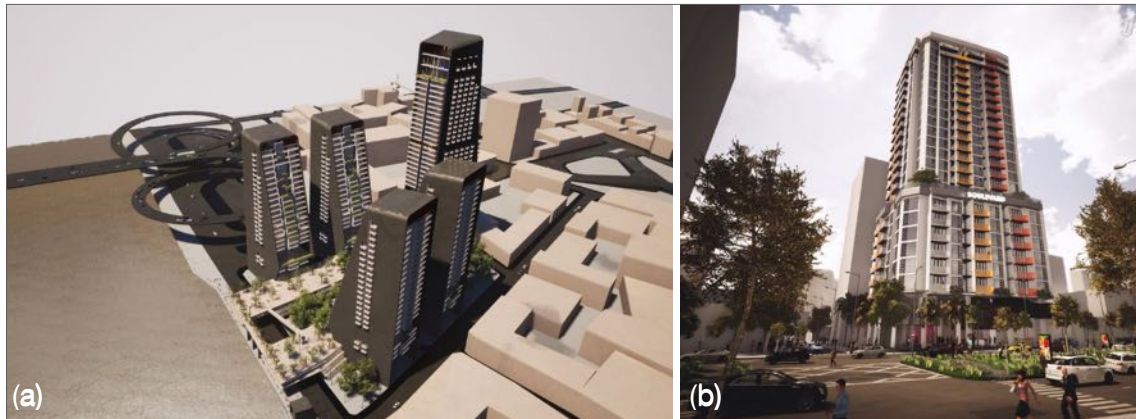


Figure 1.1: (a) Mixed-use Quartier Hai Phong, (b) Mixed-use High-Rise, new CBD Hanoi

dissertation's holistic research approach, which seeks to identify and evaluate sustainable design and planning strategies for emerging Urban Areas. The overarching aim is to enhance the long-term adaptability and systemic performance of dense urban districts by integrating climate-responsive design, socio-technical infrastructure, and systems thinking into the core of urban development. Particular emphasis is placed on interdisciplinary methods that link material construction, environmental simulation, and digital tools to support livability, equity, and resilience in Vietnam and other rapidly urbanising contexts.

1.2 Structure of the Dissertation

This dissertation is structured into six chapters.

Chapter 1 outlines the motivation behind the research and provides an overview of the current state of research in the context of urban development. It formulates the central research questions and presents both the overall structure and the methodological approach of the dissertation.

Chapter 2 offers a comprehensive analysis of the theoretical framework and the background of the research initiative “Smart Urban Areas” (SUA). Due to the thematic complexity of the topic, fundamental concepts and key terminology relevant to the research and analysis are defined and contextualised. The aim is to clarify both the theoretical underpinnings and the practical dimensions of a holistic approach to urban development.

Chapter 3 introduces the SUA research project in detail. It presents the project partners, the test sites in Hanoi, and the project timeline. Furthermore, the applied working methods and key challenges encountered during implementation are discussed, particularly those that shaped the project's progress. These preliminary phases form the foundation for the methodologies described in the subsequent chapter.

The core of the dissertation lies in **Chapter 4**, which investigates the essential preconditions for planning Smart Urban Areas through a detailed case study. A variety of methodological approaches are applied to examine interdependencies and influencing factors, with the goal of deriving relevant indicators for optimized planning strategies. This chapter is divided into sub sections, each focused on the case study of Tonkin 2 (T2) and TestBed 02 (TB2) in Hanoi. The investigations include analyses of building-integrated vegetation, statistical evaluations of building materiality and infrastructure, the use of Augmented and Virtual Reality (AR/VR) tools, the circular economy of water infrastructure and a brief assessment of construction costs. The results support the identification of optimization potential and serve as a foundation for future urban and architectural developments.

Chapter 5 is dedicated to the findings and reflections as interpretation of the results presented in Chapter 4. These findings are applied in a diverse processes to the reference building Tonkin 2, located within the Vinhomes Smart City (VSC). In addition, this chapter formulates holistic solutions and presents innovative approaches for the development of urban districts and Smart Urban Areas.

The final **Chapter 6** summarises the key findings of the dissertation and evaluates the extent to which the objectives of the SUA project have been achieved. It concludes with perspectives and recommendations for the future application of the developed methodologies in the context of sustainable urban development.

2 Framework and State of Research

The following chapter aims to investigate and determine insights into the current state of research and the background of the intended topic. This is followed by a definition of the research objectives and the formulation of the central research questions.

2.1 The Context of Hanoi and New Urban Areas

Urban development in Hanoi is increasingly shaped by large-scale, capital-intensive projects that are fundamentally transforming the urban fabric. In particular, the emergence of so-called New Urban Areas (NUAs) is associated with a profound restructuring of both the cityscape and the ecological and social composition of urban space (Hong & Kim, 2023). These high-density, mixed-use districts are being developed both on the city's periphery and within its existing core areas (see Figure 1.3), and they stand in stark contrast to Hanoi's traditional urban morphology.

Typically, NUAs follow international or Western-influenced urban development models that emphasise spatial functional separation, large-scale residential construction, and private capital investment. The aim is to create modern living environments with integrated infrastructure, shopping centers, office space, and service facilities. However, these developments are often planned in isolation from the site-specific environmental and socio-spatial conditions. Aspects such as natural ventilation patterns, urban heat stress, water infrastructure, or social diversity are frequently only marginally considered (Koch & Vu, 2020). In practice, this frequently results in deficits related to microclimatic resilience and social integration of these neighbourhoods (Le et al., 2022).

Construction is typically carried out by private developers in close collaboration with local authorities through public-private partnerships (PPPs). Since the early 2000s, Hanoi has evolved into a major site for large-scale real estate projects. Developers such as Vinhomes, BRG Group, Sun Group, and Ecopark are now key actors shaping the city's emerging landscape. Their projects comprise urban-scale structures with tens of thousands of housing units, independent energy and water infrastructure, educational facilities, parks, and smart infrastructure systems (Pham et al., 2023).

At the same time, this form of development entails significant risks regarding social exclusion, environmental stress, and spatial disparities. While certain population groups gain access to high-quality infrastructure and housing within gated communities, tendencies toward segregation from older, informally structured urban districts are intensifying (Nguyen & Harms, 2019).

A forward looking urban transformation process in Hanoi must incorporate a broader integration of climatic, social, and cultural dimensions. In particular, the inclusion of

Table 2.1: Developments in Hanoi carried out between 2000 - 2024

	Urban Areas	District	Developer	Construction time
1	Vinhomes Smart City	Nam Tu Liem	Vinhomes (Vietnam)	2018 -2025
2	Vinhomes Ocean Park	Gia Lam	Vinhomes (Vietnam)	2018 - 2030
3	Ciputra Hanoi	Bac Tu Llem	UDIC & Ciputra Group (Indonesia)	2003 - 2030
4	Ecopark	Hung Yen	Viet Hung Urban Development (Vietnam)	2009 - 2030+
5	Gamuda Gardens	Hoang Mai	Gamuda Land (Malaysia)	2007 - ongoing
6	Starlake	Tay Ho	Daewoo E&C (South Korea)	2010 - 2030
7	Times City	Hai Ba Trung	Vinhomes (Vietnam)	2011 - 2017
8	Royal City	Thanh Xuan	Vinhomes (Vietnam)	2010 - 2013
9	Sunshine City	Tay Ho	Sunshine Group	2017 - 2023
10	The Manor Central Park	Hoang Mai	Bitexco Group (Vietnam)	2016 - 2026
11	ParkCity Hanoi	Ha Dong	Perdana ParkCity (Malaysia)	2009 - 2013+
12	Splendora	Hoai Duc	An Khanh JVC (Vietnam South- Korea Joint Venture)	2006 - 2025+

climate adaptation strategies, participatory planning processes, the preservation of cultural identities, and the adoption of sustainable mobility and resource-efficient supply systems are central to enhancing the long-term resilience of new urban districts.

The large-scale urban projects depicted in Table 2.1 were implemented between 2000 and 2024 and are exemplary of the transformation occurring in Hanoi's urban environment. Table 2.1 maps the 15 largest NUAs within the administrative structure of the capital, assigning them to specific city districts and development actors. Instead Table 2.2 presents a differentiated classification framework that enables systematic comparison of key attributes, including location, function, building typology, infrastructure integration, and development status. Noteworthy is the broad spectrum in terms of planning horizon and implementation timelines: while large-scale projects such as Ciputra, Ocean Park, Ecopark, and Starlake have undergone phased development over decades and continue to exhibit further expansion potential, others, such as Royal and Time City, were completed in their entirety within a very short timeframe. At the time of reporting, BRG Smart City or Vinhomes Global Gate are still in the early stage of infrastructural development or already under construction but will not be used as examples of Hanoi's dynamic urban growth due missing data.

Table 2.2: Classification of current Urban Areas

	Urban Area	Size (ha)	Functions	Status 2025	Bldg Typology	Green Index*	Smart City Infrastr.
1	Vinhomes Smart City	280	Mixed-use / TOD	In operation	High Rise Dominance	40/60	Integrated
2	Vinhomes Ocean Park	420	Mixed-use	In operation	High Rise Dominance	20/80	Integrated
3	Ciputra Hanoi	320	Mixed-use	In operation	Mix Typology	50/50	Partly integrated
4	Ecopark	500	Mixed-use	In operation	High Rise Dominance	85/15	Partly integrated
5	Gamuda Gardens	75	Mixed-use	In operation	Mid Rise	30/70	Partly integrated
6	Starlake	188	Mixed-use	Partly in operation	Mix Typology	50/50	Partly integrated
7	Times City	36	Mixed-use	In operation	High Rise Dominance	10/90	Partly integrated
8	Royal City	23	Mixed-use / TOD	In operation	High Rise Dominance	5/95	Partly integrated
9	Sunshine City	5	Mixed-use	Partly in operation	High Rise Dominance	10/90	Partly integrated
10	The Manor Central Park	200	Mixed-use	Partly in operation	Low Rise	50/50	Partly integrated
11	ParkCity Hanoi	76	Mixed-use	In operation	Low Rise	30/70	Partly integrated
12	Splendor	265	Mixed-use	Partly in operation	Mid Rise	50/50	Partly integrated
* Green Index: unoccupied area in comparison to occupied area (by structure) in percentage (vegetated % / non-vegetated %)							

2.2 Urban Areas (UAs) versus Smart Urban Areas

In the context of rapid urbanisation across Southeast Asia, the distinction between conventional Urban Areas (UAs) and emergent Smart Urban Areas (SUAs) has become increasingly relevant. Urban Areas, as formally defined by UN-Habitat and national planning agencies, refer to spatially contiguous settlements characterised by high population density, mixed land use, and consolidated infrastructure networks (UN-Habitat, 2020; World Bank, 2019). These areas prioritise space-efficient development, often with limited ecological integration or adaptive infrastructure.

In contrast, Smart Urban Areas represent a conceptual and operational evolution of UAs. Rooted in the Smart City discourse of the early 2000s (Hall et al., 2000), SUAs

aim to embed advanced information and communication technologies (ICT), systemic sustainability strategies, and multifunctional land use into urban development. International standards such as ISO 37122 and ITU-T Y.4903 propose that SUAs be understood not merely as technology-driven zones, but as complex urban ecosystems designed for resilience, equity, and environmental efficiency (ISO, 2019; ITU, 2020). In the Vietnamese context, however, the implementation of smart city principles has been heavily directed toward ICT integration - often at the expense of ecological responsiveness or social inclusivity (Thai et al., 2021; Le et al., 2022).

- **Urban Areas (UAs):** Densely built-up zones defined by formal land use, mixed residential and commercial functions, and typical infrastructure consolidation. Development emphasis is often on high density and efficient spatial layout.
- **Smart Urban Areas (SUAs):** Evolved UA models that explicitly integrate digital technologies (ICT/IoT), sustainable resource strategies, and system-level design principles aimed at resilience and enhanced livability.

Although historically defined at varying scales, both UA and SUA practices apply a systematic analysis approach, often represented through scaling diagrams and weighting frameworks. In UA planning, the focus remains largely on physical form and land-use mix. In contrast, SUA frameworks elevate digital connectivity and real-time control systems. Yet this orientation toward ICT dominance can overshadow critical environmental and social dimensions (Hong & Kim, 2023; Thai et al., 2021).

Qualities and Dysfunctional Outcomes:

Urban Areas often suffer from microclimatic heat stress, limited amenity space, and infrastructure overload—especially in rapidly densifying cities. In contrast, Smart Urban Areas aspire to integrate circular resource use, green infrastructure, and real-time adaptability. However, they frequently remain technological marketing constructs: many SUA frameworks still emphasise data systems over functional environmental and social justice (Koch & Vu, 2020). Rather than relying solely on conventional indicators (density, wall to window ratio, floor area), the dissertation tries to advocate a broadened suite of metrics, including:

- Green area ratio (e.g. per building footprint)
- Water recirculation and rainwater harvesting indices
- Façade and rooftop greening extent
- Building–infrastructure interconnectivity (e.g. heat exchange, sensor integration, micro-climate buffering)

Observational Challenges and Critical Viewpoints:

- **Density vs openness:** UA planning tends to maximise density; SUA often prescribes distributed open space, but implementation in high-demand growth areas remains variable.
- **Infrastructure bundling vs marketing:** While SUAs promise integrated utility systems (energy grids, digital infrastructure, (water recycling)), actual practice often lags many projects use “SUA” branding without substantive implementation (Pham et al., 2023).
- **Local adaptation:** Because planning tools are frequently imported from Western contexts, they may disregard local climate, socio-cultural values, and stakeholder needs, reducing real-world resilience.

SUAs offer a valuable conceptual evolution beyond UAs, but only if digital augmentation is embedded in ecological, social, and systemic sustainability design. It is important to recognise that the development of urban districts represents a natural progression of urbanisation, evolving in parallel with broader societal transformations. Smart Urban Areas (SUAs) introduce a technological dimension to the already matured and highly dense inner-city Urban Areas (UAs). This evolution itself reflects an ongoing process - one that may initially be shaped by market-oriented narratives as mentioned beforehand but can ultimately lead to more critical reflection and substantive optimisation over time.

2.3 System Solutions and Networks

A step further, the conceptual underpinnings SUAs reveal similarities to systemic and network-based solutions that emerged in the mid-20th century. In particular, the idea of decentralised and distributive systems can be traced back to telecommunications research conducted in the early 1960s by Paul Baran at the RAND Corporation², ordered by the NASA. Baran’s seminal work on survivable communication systems introduced the notion of distributed network topologies as a means to preserve functionality in the event of partial system failure, originally conceived as a strategic response to Cold War-era threats to U.S. communications infrastructure (Baran, 1964). His diagrams of centralised, decentralised, and distributed networks remain foundational in understanding systemic resilience (Figure 2.1). While initially designed for digital data transmission, Baran’s distributed logic has since found resonance in various domains, including urban systems thinking. In the context of urban development, particularly in rapidly expanding megacities, the parallels are evident: rather than concentrating critical infrastructure in singular urban centers, resilience can

² <https://www.rand.org/pubs/articles/2018/paul-baran-and-the-origins-of-the-internet.html> (22.10.2021)

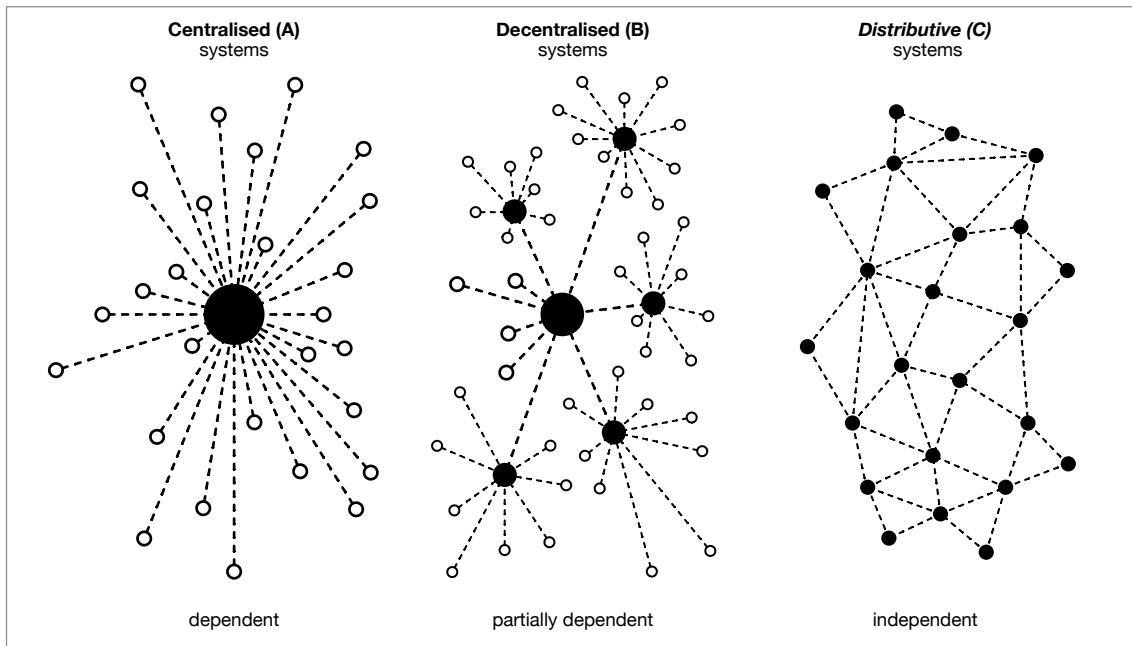


Figure 2.1: Networks by RAND (illustration based on RAND)

be enhanced by distributing essential services and functionalities across multiple interconnected nodes. This decentralisation mitigates the risk of systemic failure, enhances local autonomy, and improves the adaptive capacity of urban systems (Batty, 2013). The distributive city model echoes other progressive urban paradigms developed since the late 20th century, such as the “Green Urbanism” approach (Lehmann, 2010), the “Carbon Neutral City” (Newman & Jennings, 2008), and the “Zero Waste City” (Zaman & Lehmann, 2011). These models share a systems-based view that treats the city as a complex, dynamic organism, with feedback loops between environmental, infrastructural, and social sub-systems. (Zaman & Lehmann, 2011). These models share a systems-based view that treats the city as a complex, dynamic organism, with feedback loops between environmental, infrastructural, and social sub-systems. The idea of “mega-systems” as outlined by Hall et al. (2000) reflects this interconnectivity, advocating for the integration of digital technologies, spatial design, and ecological principles in urban planning.

Lehmann (2014) has further advanced this discourse by demonstrating how low-carbon districts can mitigate urban heat stress through the application of green roof infrastructure and ecosystem-based design. His research emphasises the potential of decentralised, building-integrated systems to act as thermal regulators, particularly in high-density cities where conventional infrastructure is overburdened. In this context, green roofs do not only serve as ecological amenities, but also operate as functional micro-infrastructures within the urban metabolism—cooling buildings, reducing stormwater runoff, and enhancing air quality at the neighbourhood scale.

In contemporary smart city research, the predominance of ICT- and IoT-centered

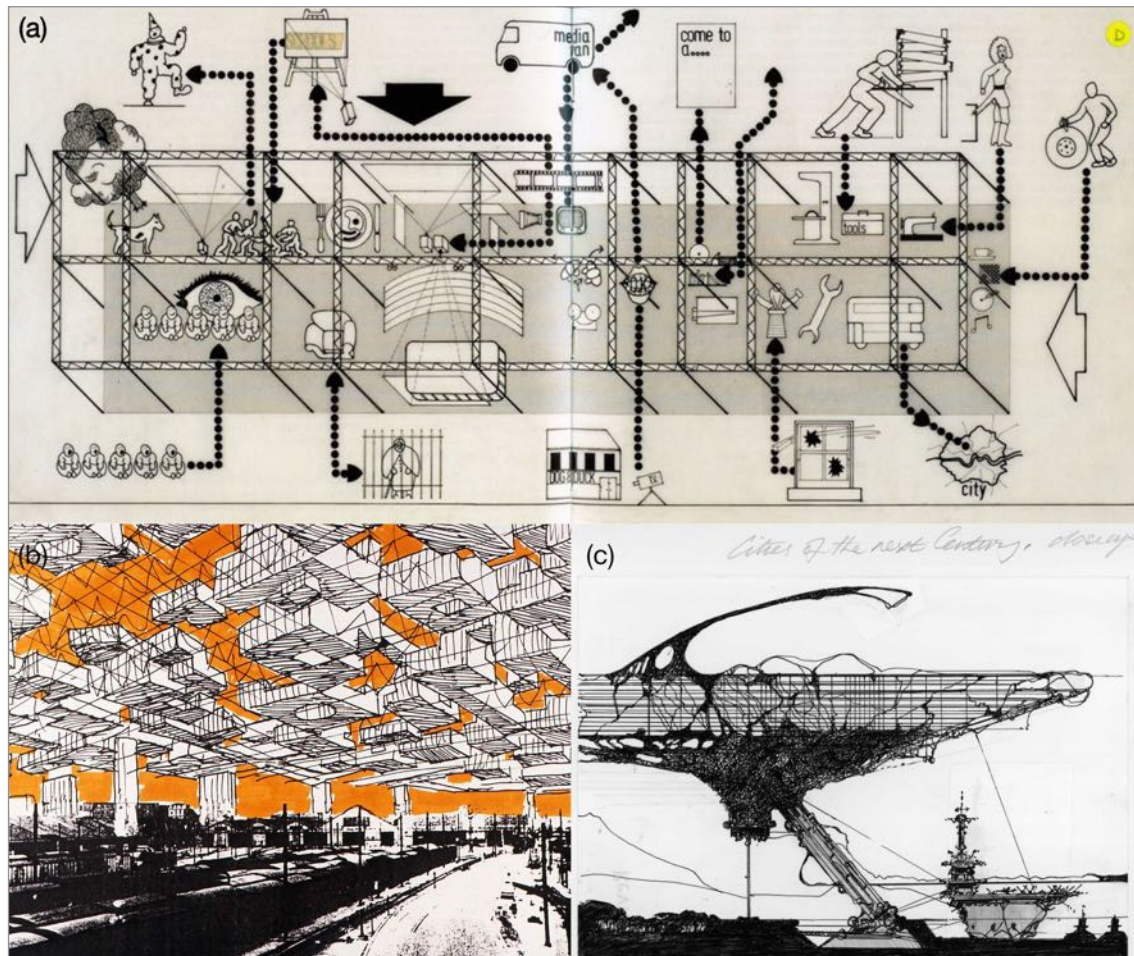


Figure 2.2: (a) Cedric Price³, (b) Yona Friedman⁴, (c) Archigram⁵

infrastructures often overarching more nuanced system-level perspectives. The deployment of sensor networks, real-time data platforms, and centralised data centers - while technically efficient - risks reproducing centralised dependencies (Vanolo, 2016). Emerging computing paradigms such as Edge Computing challenge this by localising data processing near its point of origin, thereby reducing latency, improving response times, and lowering energy loads in central servers (Shi et al., 2016). This dissertation extends these distributive principles into the architectural scale, particularly to high-rise buildings in dense urban districts. It formalises the term adaptive node to conceptualise high-rise buildings not as passive resource consumers, but as active infrastructural contributors within the broader urban system. Positioned strategically within SUAs, such buildings could decentralise critical functions - water management, energy generation, cooling, and greening - thus relieving stress from the metropolitan macro-system. For example, high-rise buildings

³ <https://www.arkitektuel.com/fun-palace-cedric-price/> (25.10.2021)

⁴ <https://vernaculaire.com/yona-friedman-ville-spatiale/> (25.10.2021)

⁵ <https://simbiosisgroup.net/wp-content/uploads/2009/02/24.jpg> (15.11.2020)

equipped with façade and rooftop greening not only support passive cooling but also enhance microclimatic conditions by generating oxygen and improving air quality in their immediate surroundings. When aggregated at scale across an urban fabric, such nodes could significantly improve urban resilience and livability, especially in megacities like Hanoi, where densification and climatic stress coincide. The shift from a centralised to a distributive systems approach - borrowed from early cybernetics and now reshaped through contemporary urban ecology - provides a theoretical foundation for reimagining high-density development not as a burden, but as an opportunity for regenerative infrastructure. By integrating technological, environmental, and spatial systems at the building level, the Adaptive Node paradigm contributes to a more resilient and equitable form of smart urbanism.

Another Insight:

Long before the term "Smart Urban Area" itself became central to contemporary discourse, a lineage of visionary system thinking had already begun to shape architectural and urban imaginaries. During the 1960s and 1970s - an era marked by technological optimism and critical engagement with the future - interdisciplinary thinkers, engineers, scientists and architects developed complex ideas around systems, networks, and infrastructural self-sufficiency based on biological organisms, such as mycelia. This period gave rise not only to the early foundations of the internet but also to speculative frameworks that deeply influenced urban theory and design. At the heart of this technological development was Paul Baran's before mentioned pioneering work. Conceived initially as a Cold War strategy to ensure communication resilience in the event of a nuclear attack, Baran's decentralised and later distributed network topology laid the groundwork for today's internet architecture (Baran, 1964). The principle was simple but revolutionary: to design systems that could withstand node failures and maintain functionality through redundancy and local autonomy - properties now essential to robust urban systems as well. These network concepts were quickly taken up by urban theorists and planners. Cedric Price's Fun Palace, Yona Friedman's Ville Spatiale or Archigram's Plug-In City (Figure 2.2) imagined buildings not as fixed structures but as adaptable systems, connected, reprogrammable, responsive and flexible. The organism analogy provides a conceptual framework that can be critically reapplied to contemporary conditions of rapid urbanisation. That is precisely why the work of ecological systems theorists Howard T. Odum (1924-2002), who applied energy loop analysis and feedback logic to urban metabolism and anticipating the later development of circular economy frameworks and regenerative urban design (Odum, 1971, 2007), is indispensable. What connects these visionaries is their shared departure from linear, top-down planning toward dynamic, multi-scalar systems capable of learning and evolving. Fred

Scharmen's recent study *Space Settlements* (2019) revisits this period of optimism by analysing NASA-commissioned visions, such as those by Gerard O'Neill⁶ (1927–1992) and the Princeton physics team. These speculative proposals projected closed-loop ecosystems and infrastructural autonomy into orbital habitats. Although visionary, and still in stark contrast to nowadays research, they reflected a radical openness toward self-regulating environments, modularity, and the interdependence of human and technical systems. Rather than treating cities as fixed hierarchies, these visions embraced the complexity of feedback-driven, adaptive networks.

In contemporary architectural research, this systems-based legacy is resurfacing in the context of Smart Urban Areas. The notion of “adaptive nodes”, buildings that do not merely consume resources but actively contribute to the performance and resilience of the urban environment, can be understood as a direct architectural response to Baran's network logic. High-rise buildings in this model function analogously to distributed servers: semi-autonomous, locally responsive, and infra-structurally embedded. They filter stormwater, generate renewable energy, or reduce urban heat through vegetative façades and rooftops, feeding microclimatic, hydrological, or energy benefits back into the urban system (Lehmann, 2014).

The growing relevance of edge computing in ICT, where data processing is decentralised to the edge of the network, further strengthens this analogy. Just as edge systems reduce latency and energy consumption by processing information locally, so too can architectural systems localise environmental control, thereby reducing dependency on centralised urban infrastructure. The building as adaptive node becomes a mediator between human activity, environmental flows, and digital systems. This work done here rather put the focus on edge computing than adopts and extends this systems logic to propose a redefinition of dense urban areas. Rather than viewing high-rise development as a stressor on urban infrastructure, the chapter argues for its reconceptualisation as a distributed infrastructural asset, capable of contributing to climate resilience, localised resource cycles, and systemic adaptability. In doing so, it situates SUAs and especially vertical structures such as high-rise not merely as ICT technoid-like zones but as potentials to a broader legacy of instrumental, integrative, and regenerative systems thinking and ultimately in the further extend as operational units.

2.4 The High-Rise Building as an Adaptive Node

Based on the investigation of adaptive networks, this section proposes to conceptualise the high-rise building as an adaptive node within a broader urban

⁶ <https://space.nss.org/the-colonization-of-space-gerard-k-o-neill-physics-today-1974/> (08.08.2025)

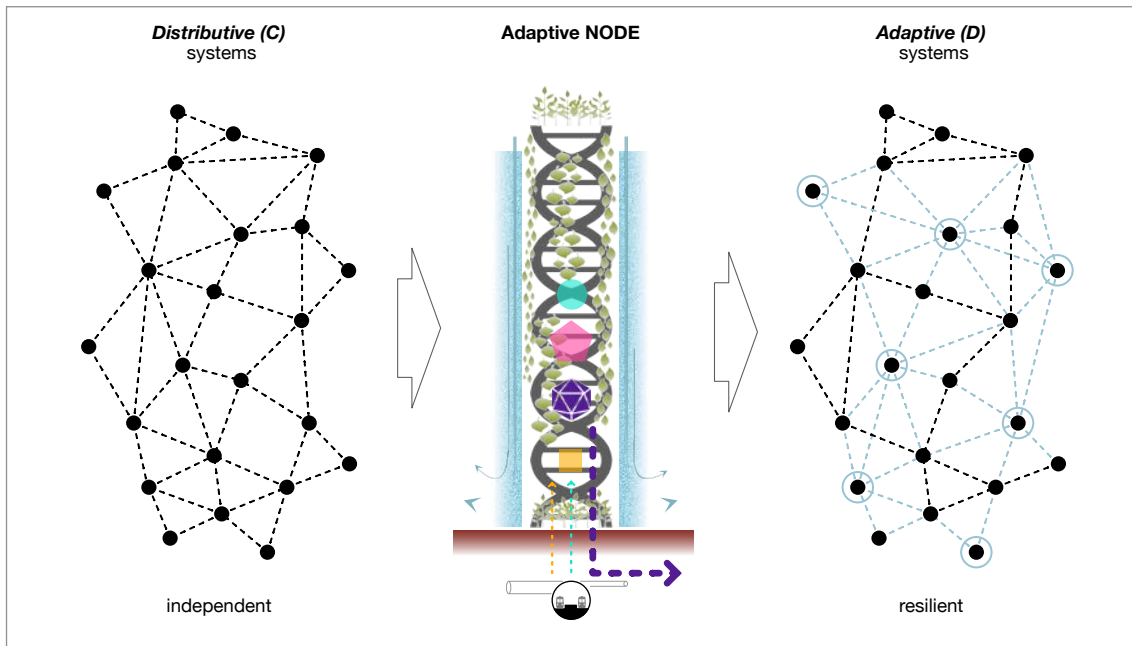


Figure 2.3: High-Rise. Adaptive Node

system - one that not only consumes energy flows and raw materials but also returns resources back into the urban macrostructure. In doing so, it becomes a fundamental building block for enhancing overall urban resilience in the face of climate change and for advancing principles of sustainable development. The high-rise is thus reimaged as a living organism - simultaneously forming a symbiotic relationship and feedback loop with its surrounding neighbourhood (Caprotti & Cowley, 2017; Sharifi & Yamagata, 2018). While core ideas of adaptivity in architecture, smart infrastructures, and network thinking have existed for decades, the explicit application of “adaptive node” logic to high-rise buildings is just emerging. Such systems logic is mirrored in the architecture of contemporary Smart Cities, where distributed energy systems, decentralized water management, and building-integrated infrastructure aim to create urban environments that are both self-sufficient and interconnected. With the increasing use of Building Information Modeling (BIM), IoT-integrated sensors, and AI-driven controls, a growing body of research is now investigating adaptive building typologies - a movement that converges with concepts of resilience and regenerative design (Loonen et al., 2013; Lehmann, 2014). In addition to that in this complex and abstract line of reasoning relates to the understanding that spatial structuring in urban systems evolves from a two-dimensional surface into a three-dimensional volume - shifting from the horizontal to the vertical. While telecommunications networks are often visualised in planar diagrams, they in fact constitute a three-dimensional system when including orbital satellite constellations, which form a spherical information shell surrounding the Earth (Baran, 1964; Graham & Marvin, 2001). A similar transformation occurs in urban planning processes. Planning traditionally begins in two-dimensional

cartographic or GIS-based formats, yet increasingly unfolds into three-dimensional spatial logic through the use of parametric tools and spatial simulations (Batty, 2013; Portugali, 2021). This transformation marks a conceptual threshold: the high-rise building becomes a critical system component that extends urban structure from the surface into vertical space (Klotz, 2020). As this domain is still relatively new in conceptual understanding, the body of scientific data remains limited and modest in scope. Nevertheless, initial examples do exist, and the Smart Urban Areas project applies this line of thinking to buildings in Hanoi, Vietnam, aiming to develop solutions specifically within zones of high-density and rapid urban transformation in the global south especially cities with tendencies to become Mega-Cities.

A seminal example in this direction is the adaptive high-rise demonstrator “D1244⁷” at the University of Stuttgart (2021), which integrates 128 strain gauges, 24 hydraulic actuators, 230V and 400V connectors, internet and modular, reconfigurable components into a 36-meter prototype tower for scientists and researchers. The building dynamically adjusts to wind loads and environmental conditions in real time and is explicitly described by its developers as an “adaptive node” in structural and climatic terms (Schumacher et al., 2022). The Stuttgart case study demonstrates that system thinking, long applied in industrial control systems, can be transferred to the architectural scale to increase not only structural efficiency but also energy performance and spatial intelligence. Aside from the above mentioned abstract-visionary besides advanced concepts and beyond adaptive facades and climate-responsive systems, high-rise buildings in SUAs can act as urban infrastructure hubs. With integrated greywater recycling, green roof and facade systems (Trudo Toren⁸, Eindhoven), solar energy production (Power Nest⁹, Eindhoven), and real-time environmental monitoring, they can contribute actively to their surrounding urban fabric - redistributing resources and improving microclimates. In a city like Hanoi, where rapid urbanization and infrastructure overload coincide, such nodal buildings may help decentralize stress, particularly in peripheral and high-density districts (Koch & Vu, 2020; Le et al., 2022). From this perspective, high-rises are no longer merely passive containers of program. Instead, they become agents within a wider regenerative network, contributing fresh air through rooftop greenery (Lehmann, 2014; Susca et al., 2011), reducing stormwater runoff through green roof infrastructure and permeable layers (Berardi, 2016), moderating heat island effects via passive thermal regulation (Sailor, 2011), and potentially sharing data and resources with nearby infrastructure as part of decentralized smart systems (Batty et al., 2012; Angelidou,

⁷ <https://www.sfb1244.uni-stuttgart.de/en/demonstrator/> (30.07.2025)

⁸ <https://www.trudo.nl/trudo-toren> (26.01.2023)

⁹ <https://www.trudo.nl/haasje-over-strijp-s/standalone-energie-dashboard> (26.01.2023)

2014). This shift in role aligns with the concept of high-rises as adaptive nodes - architectural systems embedded within and responsive to their urban and ecological context (Figure 2.3).

2.5 Modern Urban Network Approach (MUNA)

Recent urban development initiatives are increasingly focused on implementing theoretical spatial models by leveraging available data, particularly in the Global South where there is a strong emphasis on generating self-sufficient solutions for urban growth (Watson, 2009; UN-Habitat, 2020). While not yet fully integrated in Europe, these approaches are gaining traction. This section will discuss two key concepts within this framework: Mixed-Use Development and Transit-Oriented Development, and their evolution towards a modern urban network approach (MUNA).

The Mixed-Use Development (MUD) model has become a cornerstone of contemporary urban planning, aiming to create compact, walkable, and functionally diverse urban environments. MUD integrates residential, commercial, cultural, and institutional functions within the same development or neighbourhood to foster spatial synergy, reduce travel demand, and enhance social interaction (Grant, 2002; Hoppenbrouwer & Louw, 2005). As a response to suburban sprawl and a means to improve land-use efficiency and promote sustainable growth, MUD has proven instrumental in creating vibrant, livable, and resilient communities (Talen, 2005). This approach aligns particularly well with concepts like the 15-minute city, a model that could be highly suitable for a capital city like Hanoi, given its historical urban fabric, particularly the 36 streets of the Old Quarter north of Hoan Kiem Lake.

Figure 2.4 shows successful examples from Singapore, Australia, Malaysia and Japan that integrate high-rise structures - partly with green appliances - into their urban environment while combining city elements and functions into the verticality structure. Building upon the principles of MUD, the Transit-Oriented Development (TOD) introduces an additional layer of strategic coordination between land use and public transportation infrastructure. Widely applied in metropolitan areas worldwide, TOD intensifies land use around transit nodes and corridors by adhering to the principles of density, diversity, and design (Curtis, Renne, & Bertolini, 2009; Waters, 2016). The primary objective is to concentrate mobility flows, unlock cross-functional synergies, and increase the diversity of uses within walking distance of public transit (Calthorpe, 1993; Cervero, 1998). A core element of TOD is the integration of high-density residential space near transit infrastructure, which encourages public transport usage, shortens travel distances, and reduces the environmental footprint of urban mobility systems (Suzuki, Cervero, & Iuchi, 2013). This strategy not only optimises transportation efficiency but also fosters mixed-income communities, supports local

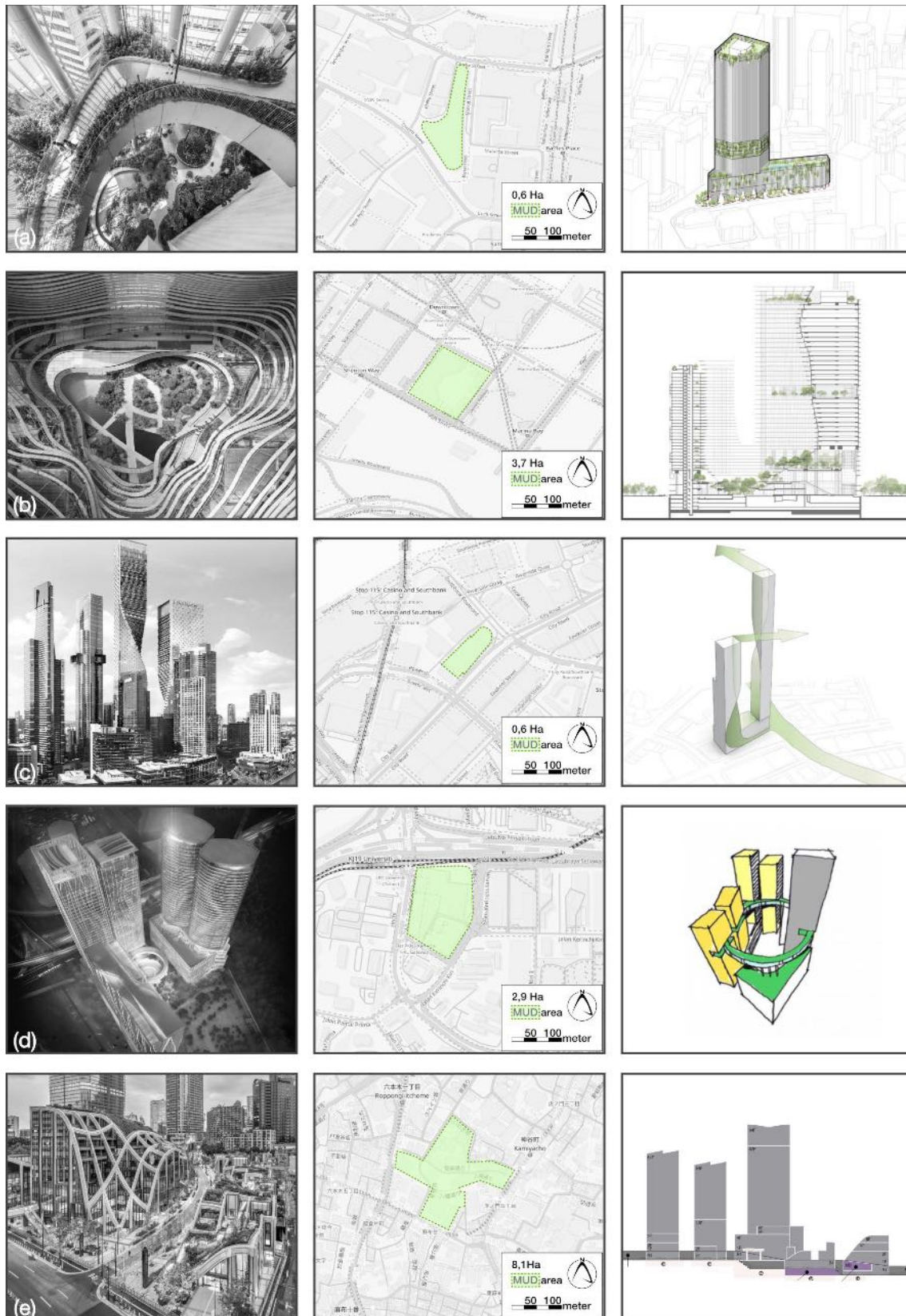


Figure 2.4: Mixed-Use Development (MUD)¹⁰, (a) CapitaSpring, (b) Marina One, (c) Southbank, (d) KL Gateway, (e) Azabudai Hills (based on Project related Sources)

¹⁰ Wardner, Pamela. (2014). Explaining mixed-use developments: a critical realist's perspective.

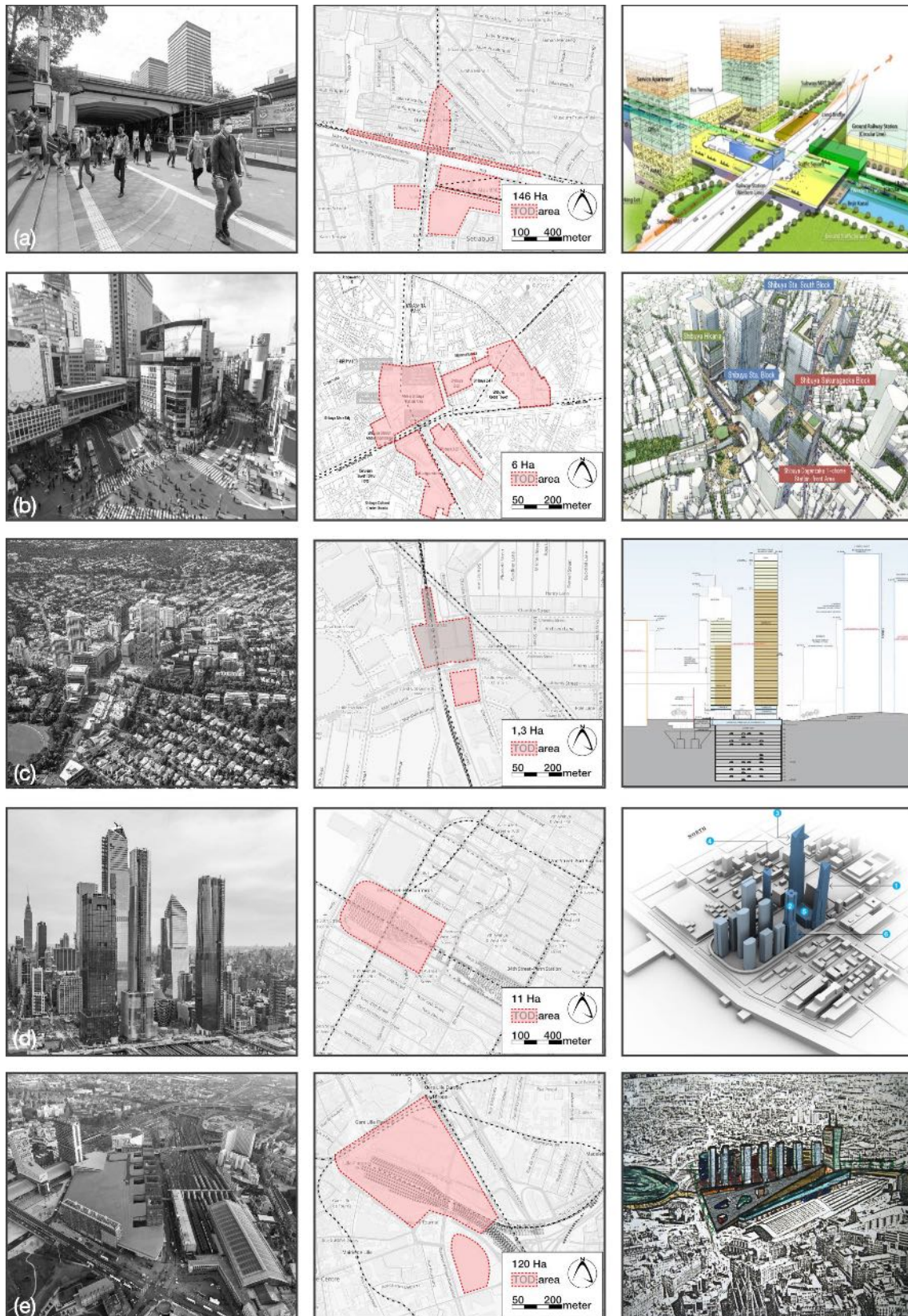


Figure 2.5: Transit Oriented Development (TOD)¹¹, (a) Dukuh Atas, (b) Shibuya Central (c) Eight Eight, (d) Hudson Yard, (e) Euralille (based on Project related Sources)

¹¹ <https://tod.itdp.org/what-is-tod.html> (20.11.2024)

economic activity, and enables the functional transformation of underutilised urban areas (Cervero & Murakami, 2009). Figure 2.5 exemplifies TOD projects from Indonesia, Japan, India, United States and France that often redeveloped and transferred previously used industrial areas within the urbanity into hub of traffic transition, interconnectivity and condensation while developing vertical structures to accommodate office, retail and residential spaces. All projects aiming for selective densification for urbanist to commute and live in short distance between private and public. In further extend several former industrial sites within Hanoi, currently undergoing redevelopment into urban areas, are ideally suited for the MUNA-inspired development approach. These sites are typically situated along strategic road axes and at key transportation nodes. Examples of such locations in Hanoi include:

- VinaTaba Factory, Nguyen Trai, Thanh Xuan, Hanoi
- Railway Factory, Ngoc Lam, Long Bien, Hanoi
- Alcohol Factory, between Nguyen Cong Tru and Hoa Ma, Hai Ba Trung, Hanoi

The redevelopment of these locations offers a unique opportunity to generate urban transport hubs both vertically and horizontally. This approach combines the principle of short distances by projecting key urban functions, for example the 15-minutes walkable city, into high-rises and establishing multi-level connectivity (Vertical City), something Nina Rappaport widely examines in her research. Furthermore, horizontal development, such as elevated pedestrian walkways and bridges that connect adjacent building structures, expands upon the concept of pedestrian-oriented development (POD). This type of urban renewal allows for the reinterpretation and integration of new urban functions – such accessible cities also allow individuals the ability to access economic opportunities (Watson, 2016). The availability of land makes it possible to reintegrate small-scale manufacturing back into the city, thereby providing accessible workplaces. This MUNA-inspired approach could significantly contribute to the resilience and climate adaptation (SDG 9, 11, 12, 13) of cities in the Global South by operationalising the Adaptive Node concept. Further successful TOD examples in Asia are prominent in global cities such as Hong Kong, Bangkok, and Manila, as well as in Japanese cities like Tokyo and Sendai, and Australian metropolises including Adelaide, Melbourne, and Sydney (Suzuki et al., 2013). In contrast, the application of TOD principles in European urbanism has been more limited. Early-stage applications have been observed in London, Paris, Berlin, and Rotterdam, while a theoretical TOD scenario was also explored in Dortmund, Germany, highlighting its potential adaptability to mid-sized cities (Riad et al., 2022). However, the implementation of TOD and MUD requires critical reflection. A number of projects have evolved into prestige-driven developments that often disregard climate-

responsive design. Even in 2024, many transit-oriented buildings are constructed with fully glazed facades, which results in significant solar heat gain and high cooling demands. A notable example is Hudson Yards in New York City, an emblematic TOD project that has been criticised for its excessive solar exposure and minimal environmental adaptation (Pinto, 2022).

A key deficiency in many TOD and MUD projects is the lack of vertical greening and bioclimatic integration. The pioneering work of Ken Yeang in ecological design is particularly relevant here. As early as the 1980s, Yeang developed the concept of the “bioclimatic / biophilic skyscraper,” which proposes that tall buildings should function as vertical ecosystems by integrating green facades, sky gardens, natural ventilation, and passive energy systems (Yeang, 1996, 2006, 2011). His designs, such as the Menara Mesiniaga in Malaysia, demonstrate how vegetation and ecological principles can be structurally and functionally embedded into high-density architecture. Yeang’s research also emphasises biomimicry, where the built environment reflects the behaviour and adaptability of natural systems (Yeang, 2011).

Building on this foundation, the expansion of TOD into Green Transit-Oriented Development (gTOD) and MUD into Green Mixed-Use Development (gMUD) offers a forward-thinking strategy to reposition these dense urban nodes as climatically and ecologically active infrastructure besides its potential for circular economy. By integrating vegetated façades, rooftop landscapes, and building-integrated ecosystems, these developments could function as urban cooling systems, improving microclimate regulation, air quality, and overall urban resilience and livability.

Both MUD and TOD are in their nascent stages of integration in Vietnam. Nevertheless these trends are currently a subject of strategic discussion across Southeast Asia (SEA) at conferences such as the OECD & International Transport Forum (2023)¹². This highlights the immense pressure faced by cities in the region and the significant effort being directed towards identifying sustainable and reliable solutions for urban development. As NUAs are developed over the next decade to meet the high demand for urbanisation, the principles of MUD, TOD and further extend MUNA will play an crucial role in fostering sustainable urban development.

2.6 Research Objectives and Key Question

The central objective of this dissertation is to enhance the conceptual and functional understanding of urban districts as dynamic, adaptive systems within the broader urbanity. By investigating their capacity to serve as interfaces between high-rise structures, neighbourhood units, and metropolitan infrastructures, the research aims

¹² <https://www.itf-oecd.org/sites/default/files/docs/transit-oriented-development-accessibility-southeast-asia.pdf> (08.08.2025)

to uncover scalable strategies that alleviate pressure on centralised systems while reinforcing climate resilience and socio-spatial cohesion.

The applied methodologies are tested through site-specific case studies in Hanoi, Vietnam, where high urban density, climate exposure, and rapid spatial transformation offer a complex but instructive testing ground. These case studies are not only intended to reflect the practical relevance of implemented measures - such as decentralised water treatment, green envelope systems, and real-time sensor monitoring - but also to critically interrogate their systemic effects within the district and the city as a whole. Through an integrative approach combining empirical data, digital modeling, and urban systems theory, the study seeks to identify adaptive strategies that align local interventions with global sustainability objectives. Particular emphasis is placed on the interdependencies between buildings and infrastructures, the resilience of urban ecosystems, and the need for context-sensitive design in the Global South (Ahern, 2011; Leach et al., 2012; Bai et al., 2016). The research is situated within current discourses on urban metabolism, nature-based solutions, and smart infrastructure, with the overarching goal of contributing to a systemic perspective on future-proof urban development. By aligning field-tested methodologies with analytical evaluation, the dissertation aims to deliver applicable knowledge for practitioners and policymakers engaged in the sustainable transformation of urban areas.

Key Research Question:

In which ways can urban districts and especially high-rises function as adaptive interfaces within complex mega-systems to reduce infrastructure stress and strengthen urban resilience through site-specific interventions?

This guiding question reflects a multi-scalar perspective that acknowledges the nested nature of urban systems - from building envelopes and neighbourhood infrastructures to wider city-wide and regional networks. It also assumes that resilience is not a static condition but a dynamic capacity for transformation, requiring integrated approaches that combine technological, ecological, and socio-cultural dimensions (Meerow et al., 2016; Wilkinson, 2012). The present study conceptualises buildings as organisms - adaptive systems that not only consume resources but are also capable of returning part of these resources to the wider urban system. Figure 2.6 illustrates the spectrum of existing systems within cities. While automobiles rely on fossil or non-fossil energy sources that must be replenished externally, trains operate on decentralised energy inputs that generate traction directly at the axles. At a larger scale, cruise ships combine the characteristics of vehicles and buildings: they are mobile, relatively self-

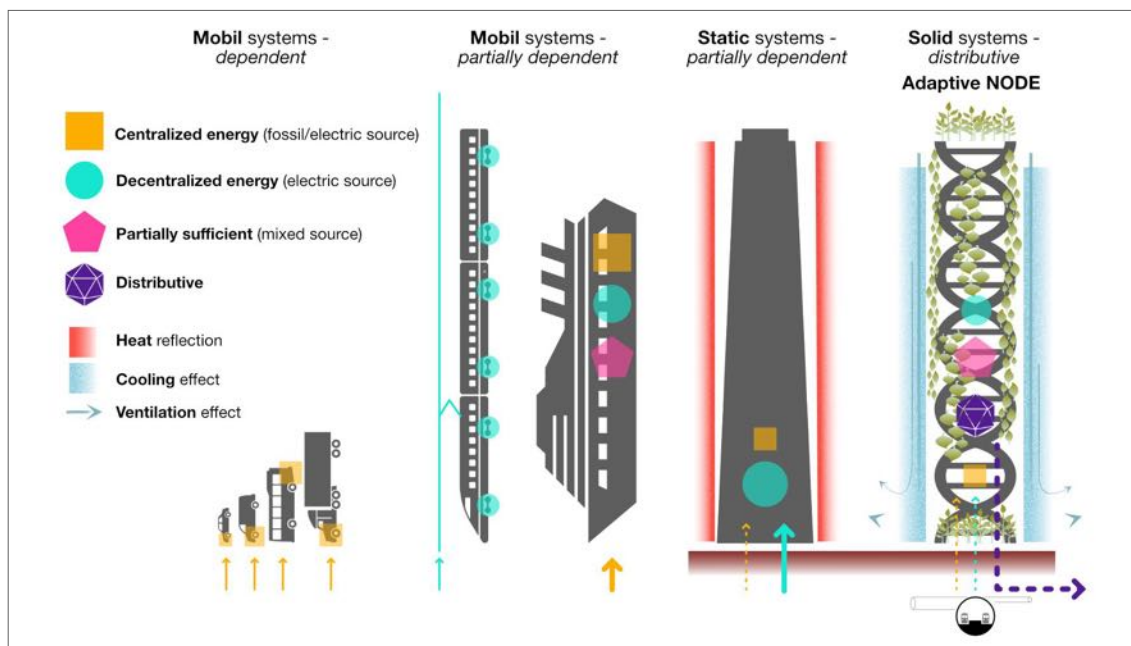


Figure 2.6: Methodology of the High-Rise as an Adaptive Node

sufficient, and require fossil fuels to secure decentralised electricity generation. Onboard, water and wastewater are partially treated and reintegrated into the operational cycle - a feedback loop absent in conventional vehicles.

In structural analogy, an inverted cruise ship resembles a high-rise building: fixed in place, immobile, and dependent on municipal resource provision, with fallback reliance on fossil energy. Most contemporary high-rises primarily act as consumers of electricity and water, discharging wastewater directly into centralised sewer systems, while on-site treatment and reuse remain rare. Particularly in urban districts of the Global South, including the study area, high-rises therefore function predominantly as resource sinks. Yet the cumulative potential of these structures is immense - for example, decentralised water treatment could provide irrigation for adjacent green spaces.

Current high-rise typologies also contribute to urban heat islands (UHI) effects through the exhaust heat of facade-mounted air conditioning units and internal thermal loads. The final step of the diagram (right-hand side) proposes a reconceptualisation: The high-rise is framed as an autonomous organism within the urban quarter and, at macro scale, within the metropolitan system. In this scenario, building materials and operations adapt resource flows and dependancies in such a way that filtered water for instance can be redistributed locally. At the same time, a fully green adapted building envelope act as a carbon sink and as a “cooling fin” rather than a “radiator” within the urban district. Scaled across the multitude of towers in megacities, such an approach could generate “cooling islands” that not only counteract heat stress but also foster biodiversity, supporting insect and bird grow rates. This potential forms one

of the central dimensions of the present investigation towards the understanding of High-rise building as an adaptive node.

3 Project Context and Case Studies

As a transition to Chapter 4, which outlines the applied methodologies, this chapter provides an overview of the overarching research initiative “Smart Urban Areas (SUA) - Sustainable System Solutions for Urban Development” in the capital city of Hanoi. This chapter introduces the specific case study sites - Tonkin 2, TestBed 1, and TestBed 2 - while also mapping the project timeline, highlighting key milestones, and outlining the challenges and limitations encountered throughout the research process

3.1 Research Project Smart Urban Areas

This dissertation is embedded within the broader research initiative *Smart Urban Areas (SUA) – Sustainable System Solutions for Urban Development* in Hanoi, Vietnam. The project, designed as a Public–Private Partnership (PPP), is jointly led by TU Dortmund University, WILO SE, and Vinhomes, with funding provided by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), nowadays the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) under the Export Initiative for Environmental Technologies (EXI)¹³. Grant administration was conducted by the federal agency *Zukunft – Umwelt – Gesellschaft* (ZUG) located in Berlin, Germany.

The project commenced in September 2022 and is scheduled to conclude in December 2025. Its overarching aim is to test climate-adaptive and resource-efficient system solutions for rapidly urbanising contexts, with Hanoi serving as an exemplary case. TU Dortmund University (TUDO) provides scientific leadership through the Chair of Spatial Information Management and Modeling (RIM), responsible for research design and methodology. WILO SE contributes technical expertise in decentralised water recycling and smart pump systems, while Vinhomes provides access to representative high-rise structures within its Smart City development. Local partners and subcontractors support the research project (Figure 3.1).

The research agenda is explicitly aligned with the UN Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). The project is organised into 17 interrelated work packages, integrating empirical fieldwork, technological implementation, and urban systems analysis.

¹³ <https://www.exportinitiative-umweltschutz.de/projekte/sua> (31.12.2025)

3.1.1 Academic Leadership

The lead academic institution is TU Dortmund University, specifically the Chair of Research Group of Spatial Information Management and Modeling (RIM), directed by Prof. Dr. Nguyen Xuan Thinh. The chair is responsible for overall project leadership, research methodology, and scientific oversight. The project research team coordinates and execute the tasks required.

The project's research agenda aligns closely with the UN Sustainable Development Goals (SDGs) named down below:

- SDG 6: Clean Water and Sanitation
- SDG 9: Industry, Innovation and Infrastructure
- SDG 11: Sustainable Cities and Communities
- SDG 12: Responsible Consumption and Production
- SDG 13: Climate Action
- SDG 17: Partnerships for the Goals

The project is organised into 17 interrelated work packages, each contributing to the project's integrative methodology and cumulative knowledge generation.

3.1.2 Industry Partner

Founded in 1872 as the "Kupfer- und Messingwaren-Fabrik Louis Opländer," WILO SE is a family-owned German manufacturer headquartered in Dortmund city. With a global workforce of 9,000 employees, WILO is a market leader in fluid management technologies, particularly in the water and building services sector. Digitalisation has played a central role in WILO's international expansion and innovation strategy. WILO's longstanding cooperation with TU Dortmund laid the foundation for its participation in the SUA project. The company brings technical expertise in energy-efficient pumping systems, membrane-based water recycling technologies (MBR), and intelligent system integration for sustainable urban infrastructure. The SUA project serves as a testing ground for the latest generation of WILO's smart water pumps, adapted to the subtropical climate of Hanoi, based on that a system solution for urban areas and smart urban areas could be established.

In this context, WILO is responsible for the design and installation of:

- High-efficiency pumps
- A building-integrated MBR water filtration unit (in cooperation with its subsidiary Abionik GmbH)
- Rainwater and grey water treatment infrastructure for irrigation of green roofs and facades

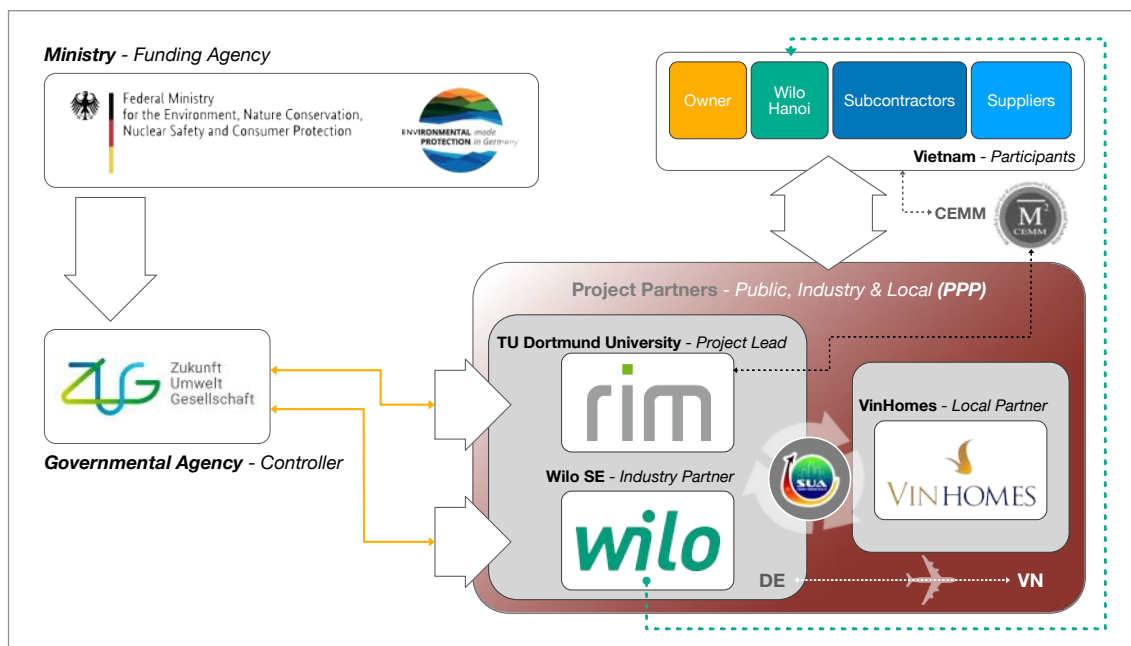


Figure 3.1: Research Project Structure

3.1.3 Local Partner

Vinhomes, a subsidiary of the Vingroup conglomerate with over 40,000 employees, is Vietnam's largest real estate developer. Its portfolio includes integrated urban townships and satellite cities across the country's most populous regions, targeting the mid residential market. Due to its market share and economic influence, Vinhomes plays an active role in shaping building codes and urban planning regulations in Vietnam. Within the SUA project, Vinhomes provides the Tonkin 2 high-rise in Vinhomes Smart City (VSC), Hanoi, as a key case study building. The tower serves as a hybrid testbed for empirical data collection, digital modeling, and the conceptual development of localised system solutions for sustainable high-rise design.

The shared objective of the collaboration is to design and implement climate-adaptive, resource-efficient solutions tailored to the dynamics of rapidly urbanising environments, as exemplified by the standard development strategies of Vinhomes. Through a scenario-based methodology, the project addresses both ecological and economic imperatives, with the goal of generating scalable models that enhance urban resilience, promote energy-conscious development, and mitigate stress factors affecting residents, buildings, and the wider urban system.

3.2 Case Studies Overview

The capital city of Hanoi, Vietnam is located at latitude 21.028511° N and longitude

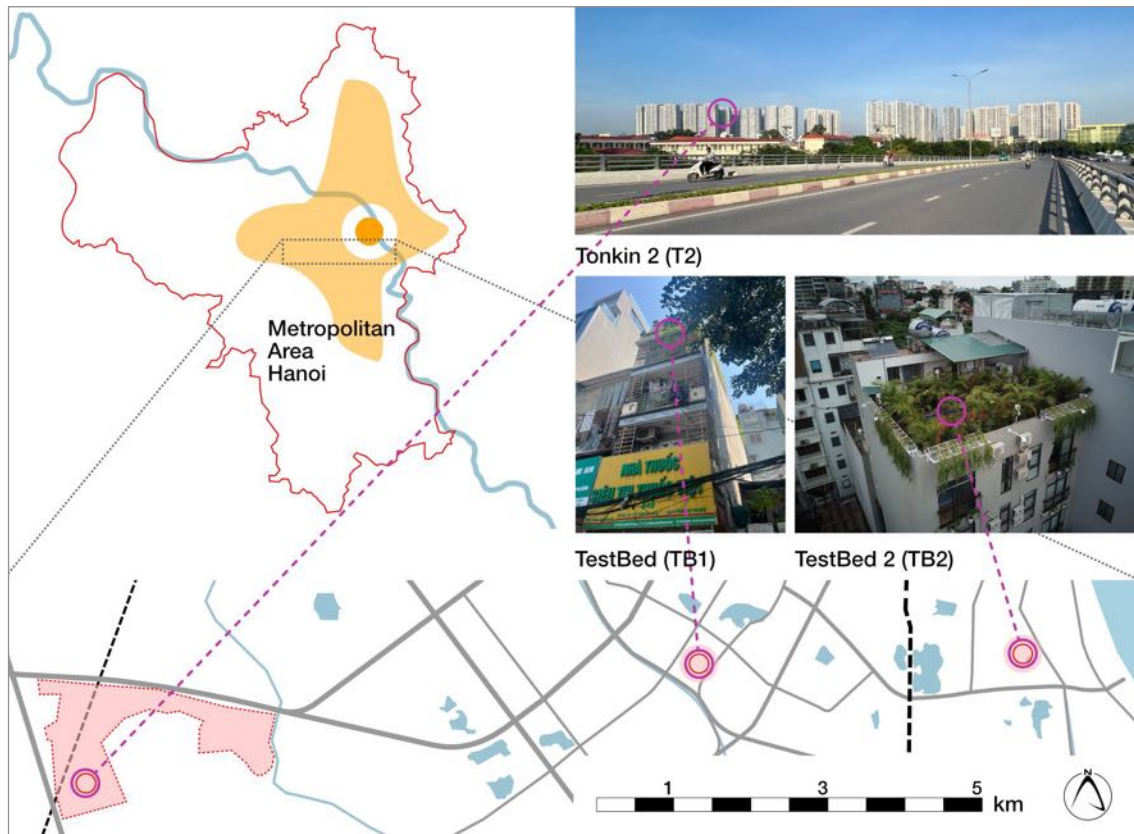


Figure 3.2: Case Study Locations within the Urbanity of Hanoi

105.804817° E, encompassing a metropolitan area of approximately 3,359 sq. km. With a population nearing ten million¹⁴ by at least 2030, Hanoi qualifies as a megacity. Government planning documents for 2030 and 2050 outline an ambitious strategy for urban expansion. Over the past decade alone, more than 50 new high-rise clusters and urban districts have been gradually developed. These urban building blocks are designed to accommodate rapid population growth, yet they simultaneously contribute to challenges such as intensified urban heat islands and increasing traffic congestion. In contrast, the development of accompanying infrastructure - particularly in the domains of mobility and transportation - has lagged behind, creating considerable strain on the city's overall resilience. Against this backdrop of rapid transformation, the SUA research project applies its methodologies to three real-world case studies in Vietnam to assess and analyse the multifaceted interactions between urban form, climate, and society. Figure 3.2 provides a spatial overview of the three case studies within the urban fabric of Hanoi, illustrating both their strategic distribution and the spectrum of challenges they address within the research framework:

- **Case Study 1: Tonkin 2 (T2)**

¹⁴ <https://en.vietnamplus.vn/hanoi-plans-to-transform-into-a-global-hub-by-2045-post307883.vnp> (02.08.2025)

Located within the Vinhomes Smart City (VSC) in the Tay Mo District, western Hanoi, this high-rise tower sits along the CT03 arterial road to Hoa Binh (Coordinates: 21.004720° N, 105.740911° E). As a representative building within the Vinhomes Smart City Hanoi urban area, TONKIN 2 serves as a testbed for investigating smart building performance and system scenarios in a high-density urban context.

- **Case Study 2: TestBed 01 (TB1)**

Situated at 82/80 Yen Lang, Lang Ha in Dong Da District (Coordinates: 21.012081° N, 105.815323° E), this location provides an inner-city microclimatic contrast and allows for the deployment of compact green infrastructure strategies under spatial constraints applied on traditional tube houses that represent the majority of building types in Hanoi.

- **Case Study 3: TestBed 02 (TB2)**

Located at 21/35 Nguyen Cong Tru, Dong Nhan in Hai Ba Trung District (Coordinates: 21.013569° N, 105.855225° E), this site serves as the project's central blueprint for data-driven analysis and experimental implementation. As the most technically instrumented case, TestBed 02 supports sensor-based monitoring, performance evaluation of green infrastructure, building envelope analysing and building-environment feedback modeling. It plays a key role in generating valid, transferable data for wider scientific analysis.

3.2.1 Case Study 1: Tonkin 2

The T2 building (Figure 3.3) represents a standardised high-rise model within the Vinhomes Smart City development in Hanoi. It serves as a core component of the serially produced residential blocks within the district. Designed as a modular and replicable system, this building typology has been implemented in multiple identical configurations across various developments throughout Vietnam. This widespread application makes it a symbolic and important case study for examining the system-based approaches to modern standardised residential construction. With an average construction period of approximately 18 months to turnkey delivery, the building exemplifies the efficiency of industrially optimized planning and execution processes.

The structural system is based on a reinforced concrete skeleton frame with load-bearing cores. Non-load-bearing walls, constructed from fired solid bricks (2-hole), are traditionally built and cement-plastered. The building's exterior is characterised by light-coloured façades with brown-toned accents, resulting in a cohesive yet visually articulated urban fabric within the urban area. Identical building types are also found in other developments in Hanoi i.e. Vinhomes Gardenia, Vinhomes Oceanside or Vinhomes Parkside.

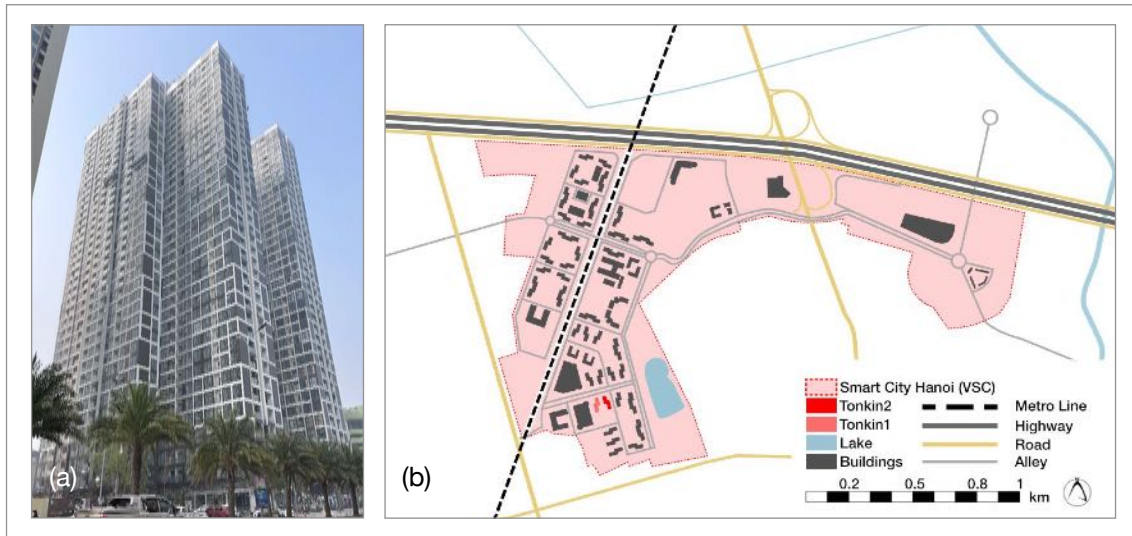


Figure 3.3: (a) Tonkin 2 and 1, (b) Site Plan of the VSC 2023

General Building Information

- Designation: Tonkin 2
- Location: Vinhomes Smart City, Nam Từ Liêm, Hanoi
- Typology: Residential High-Rise
- Function: Residential apartments, communal areas, technical rooms

Key Construction Parameters

- Total height: approx. 145 meters
- Number of stories: 39 full above-ground floors
- Basement levels: 1 (underground parking, technical infrastructure)
- Construction type: Reinforced concrete frame with load-bearing cores
- Façade system: Non-load-bearing solid brick (2-hole), cement-plastered
- Rooftop use: Primarily for HVAC and water storage equipment

Residential Configuration

- Total residential units: +- 600 units per building, depending on configuration
- Apartment sizes: 1 - 3 bed rooms (BR), ranging from 35 to 100 m²
- Floor plan layout: Central corridor with bilateral access; centrally located elevator core
- Vertical circulation: 6 elevators, including 1 service elevator
- Communal spaces: Lobby, waste collection station, underground parking access, community room

Technical Features

- Air conditioning: Individual split AC systems per unit
- Hot water supply: Central boiler systems located on the rooftop
- Security: 24/7 CCTV surveillance, biometric access control (facial recognition/fingerprint)

- Smart technologies: Smart metering (electricity/water), remote control via app, IoT-based sensors for energy use and air quality
- Greening elements: Ground-floor landscaping and vegetation

Construction Timeline

- Construction start: late 2020
- Structural completion: Mid-2022
- Interior works & commissioning: Phased during 2022–2023
- Planned full occupancy: T2 in use since mid 2023; district-wide expansion continuing through 2025

Consumption / Key Data (based on data available (not provided by local partner))

- Concrete: Reinforced concrete:
- Brick: Traditional backed bricks:
- Inhabitants: It ranges from 1.560 to 1.992 (depending on occupancy)
- Water: Table 3.1, 130 L/day/capita¹⁵
- Electricity: Table 3.2, average data by 2023¹⁶

The TONKIN 2 Tower serves as the initial subject for this investigation, as its design and operation allow for the exploration and application of optimization strategies.

Table 3.1: Occupation and Consumption per capita T2

	Qty.	Factor Min.	Min. Occupancy	Factor Max.	Max. Occupancy
Studio	111	1,0	111	1,0	111
1 Bed Room Apt.	111	1,5	166,5	2,0	222
2 Bed Room Apt.	296	3,0	888	4,0	1.184
3 Bed Room Apt.	74	5,0	370	6,0	444
	592		1.535,5		1.961
Water consumption 47,45 m³/year		m ³ /y	72.859	m ³ /y	93.049
Water consumption per day		L/d	234.000	L/d	298.000
Electricity consumption 2,766.5 kWh/year		kWh/y	4.247.961	kWh/y	5.425.107
Electricity consumption per day		kWh/d	11.823,90	kWh/d	15.098,26

¹⁵ <https://vietnamfocusguide.com/blog/how-much-water-does-vietnam-use-daily/> (06.08.2025)

¹⁶ <https://www.worlddata.info/asia/vietnam/energy-consumption.php> (06.08.2025)

These strategies can be tested either through practical implementation or conceptualised via simulations. Given its scale and consumption metrics, the tower can be understood as an "adaptive node," a concept that can be extrapolated to interpret the entire cluster of similar building typologies within the Smart City as a single, cohesive unit. In addition, the T2 building is important for scaling factors, as it allows for the testing of results and the transfer of findings at the end of this research.

3.2.2 Case Study 2: TestBed 1

TestBed 1 (TB1) is located in the inner-city district of Dong Da, situated within a narrow alleyway - a typical characteristic of the plot layouts in Hanoi. This location was specifically chosen to examine the methodology of green roof and facade systems on a manageable scale. The system integrates rainwater harvesting to automatically irrigate a selection of native plant species. The primary challenges in implementing this system on an existing, twenty-year-old building were the gathering, storage, and reintroduction of rainwater. The building stands typologically representative of the majority of Hanoi's "tube houses". A key challenge was the complete absence of architectural or structural plans for the building. Through on-site measurements, schematic drawings, and empirical knowledge, a digital model of the structure was successfully created.

The four-story residential building is 3.30 meters wide, 17.83 meters long, and reaches a height of 20 meters. Rooms are located on either side of a central staircase, and centrally arranged bathrooms, along with the staircase, form the building's structural core. The building was constructed with a typical reinforced concrete frame, with traditional fired bricks filling the wall surfaces to form the exterior envelope. Plastic-framed windows are integrated into the punched facade, and balconies are arranged on the northern side of each floor. The rooftop is finished with square terracotta tiles.

The research area is located on the flat roof of the fifth level. Here, a 16 m² area was planted with four native Vietnamese plant species within a soil container system (chapter 4.4), thereby replacing an existing green corrugated iron roof as a natural shading element. The southwest facade was equipped with hanging plants descending from the roof and is intended to be fully covered with vegetation over time. The automated irrigation system is supported by the rainwater harvesting setup in conjunction with a Wilo pump.

For continuous monitoring of meteorological conditions, a Davis Vantage Pro2 Plus - wired - weather station was installed on the rooftop ventilation and daylight attachment. This station provides information on:

- Air temperature and humidity
- Wind direction and speed

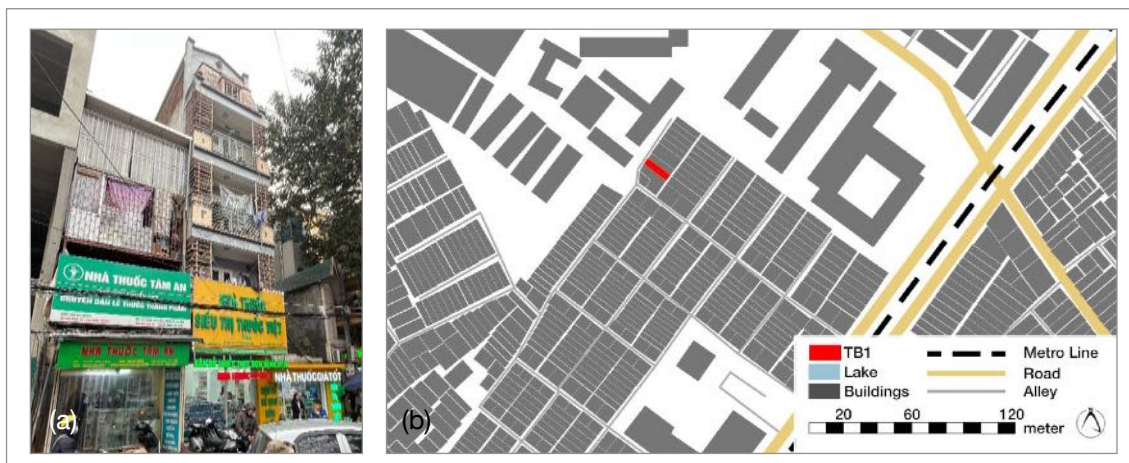


Figure 3.4: (a) TB1 North Elevation, (b) Location in Yen Lang Area

- Solar and ultraviolet radiation
- Precipitation levels

The station collects and stores this data in a cloud-based system via a central gateway at five-minute intervals. The accumulated daily datasets ranges in kilobyte size and can be viewed directly on a smartphone via the Weatherlink app or exported in .CSV format for detailed analysis (Schaefer et al., 2024). Overall, TB1 provided valuable empirical in-depth information into the local implementation of green infrastructure technologies under real-world conditions and laid the groundwork for scaling methods to other buildings in the SUA framework. The systematic approach at TB1 illuminates granular views in the on-site implementation of practices, technologies, and neighbourhood communication. As a relatively small component within the overarching system, it offered detailed knowledge at micro scale, a foundation without which scalability and transferability would risk remaining imprecise and unreliable. In the matter of building condition challenges TB1 was dismantled and moved to an interim location in Long Bien to become TB6 which is not part of this work.

3.2.3 Case Study 3: TestBed 2

The research area of TestBed 2 (TB2) is located on the rooftop and facade of a seven-floor residential building situated in the densely built-up Hai Bà Trưng District of Hanoi (105.8552° E, 21.0135° N), south of the historic Old Quarter and within walking distance of Hai Bà Trưng Lake (Ho Hai Bà Trưng). Densely in the case of Hanoi TB2 stands for a site area of 0.9 - 1.0. Completed in February 2024, the building stands approximately 25 meters tall from street level on a slight slope. It contains seven residential floors, with a total of twenty studio apartments, two two-bedroom apartments, and a three-bedroom owner's unit on the seventh floor. The apartments



Figure 3.5: (a) TestBed 2 North Elevation, (b) Location in Hai Ba Trung District

are currently managed by a rental apartment service provider. Table 3.2 explains the estimated occupation and consumption per capita. Each floor covers 143 square meters, giving the building a gross floor area of 1,144 square meters from the first to the eighth (rooftop) floor. The 143-square-meter basement floor serves as a garage, storage, fire fighting access and houses a water treatment unit. Due to the building's location in a narrow alley, the basement is only accessible by bicycle or motorbike. The elevated ground floor accommodates the entrance lobby and provides vertical access to the residential units via an elevator. A fire escape stairwell, positioned next to the elevator core, connects all floors from the rooftop to the basement, which is accessed via an exit ramp. Consequently, the permanently open ramp and stairwell provide natural ventilation throughout the building.

The building is oriented along a north–south axis and is based on an L-shaped footprint (Figure 3.5). The narrow northern wing contains studios only, the ramp, and the main entrance to the building. The southern wing, laid out as a square plan, contains the main circulation core, the fire stairwell, and additional studio besides two-room apartments, with the latter oriented toward the south. Along the full width of the southern facade, the building is set back 1.5 meters from the property boundary, creating a ventilation shaft that is not connected to the basement and therefore lacks openings necessary for continuous air circulation. The building is bordered on three sides by neighbouring structures. To the north, an adjacent building reaches up to the fifth floor. On the eastern side, neighbouring structures rise to the sixth floor and, in the southeast, even exceed the test building by two additional floors. To the south, a neighbouring building reaches the height of the fifth floor, with an enclosed air gap of 1.5 meters, while buildings to the west extend only to the height of the first floor. The southern and western facades remain largely uncovered and are directly exposed to the local climatic conditions and solar radiation in particular. The southern façade exhibits a wall-to-window ratio of 40:60, resulting in high solar exposure for the rooms

Table 3.2: Occupation and Consumption per capita TB2

	Qty.	Factor Min.	Min. Occupancy	Factor Max.	Max. Occupancy
1 Bed Room Apt.	20	1,0	20	2,0	40
2 Bed Room Apt.	2	2,0	4	4,0	8
3 Bed Room Apt.	1	4,0	4	6,0	6
	23		28		54
<hr/>					
Water consumption 54,75 m³/year		m ³ /y	1.533	m ³ /y	2.957
Water consumption per day		L/d	4.200	L/d	8.101
Electricity consumption 2,766.5 kWh/year		kWh/y	77.462	kWh/y	149.391
Electricity consumption per day		kWh/d	212	kWh/d	409

located behind the glazing. In contrast, the western facade is largely closed, with a wall-to-window ratio of 95:5, containing only small ventilation openings for the emergency stairwell. All exterior wall cores are constructed using 110 mm brick masonry, and the surfaces are finished with cement-based plaster of 10-15 mm thickness. The test building itself is painted in a warm beige-grey tone while the shaded northern facade is painted white. The rooftop on the eight floor houses the technical core that accommodates access to the elevator shaft, a small prayer room, a restroom, a loggia facing north and the landing of the fire escape stairwell. On this particular roof attachment, two water tanks - each with a capacity of two cubic meters - are installed for the tenants, along with a solar thermal collector for the home owner and besides various pipe systems, and pumps. The floor is paved with traditional terracotta tiles 300 x 300 mm typical of the Hanoi urban housing. The main rooftop terrace on the eighth floor covers an area of 103 m² and is also fully covered with terracotta tiling used for flat roofs in Hanoi. A 1.10-meter-high parapet wall encloses the terrace on the east, south, and west sides. In 2024, the neighbouring building to the east was completed, rising two floors above the height of the test building. A freestanding metal shed covered by corrugated sheet metal using a green coating shelters an area of approximately 20 m² that accommodates washing machines, dryers, and the glass cover of the light well. The elevator shaft connects the floors from basement up to the seventh floor. Access to the roof top is available through the emergency stairwell. Access to the water tanks on top of the roof attachment is possible by using a mobil ladder. Along the central axis of the southern elevation,

outdoor air conditioning units are vertically aligned from the ground floor to the seventh floor. The air conditioning outdoor units belonging to the northern oriented studio apartments are wall mounted on individual metal brackets. The design and construction of the building - characterised by full lot utilisation - are typical of urban residential architecture in Hanoi since the early 2000s, making it a representative case study for testing the performance of green roofs and facades under real-life conditions. A further advantage for this research lies in the fact that the rooftop is still largely undeveloped, offering favorable conditions for experimental implementation. Similar to TB1, for continuous monitoring of meteorological conditions, a Davis Vantage Pro2 Plus weather station - wireless - was installed on the rooftop staircase attachment. This station provides information on:

- Air temperature and humidity
- Wind direction and speed
- Solar and ultraviolet radiation
- Precipitation levels

In addition to the weather station, a network of Davis Nodes and environmental sensors was installed across the green roof and façades to monitor key parameters such as soil moisture, leaf wetness, surface temperature, and relative humidity. This sensor infrastructure provides empirical data to assess the performance and resilience of the vegetated building envelope under real conditions. In a subsequent project phase, the automated irrigation system was linked to the building's integrated water treatment unit, located in the basement, which filters and reuses grey, black and rain water. This connection effectively established a closed-loop water cycle within the building, aligning with principles of circular resource management.

The implementation of the proposed methods - from the initial contact with the building owner to the installation of the green roof - was completed within a four-month period, between April and July 2024. In addition TB2 not only fulfilled the structural prerequisites for the practical implementation of the project's assumptions and scenarios on a manageable scale, but it also offered a degree of architectural flexibility that was not available at T2 or TB1. Due to the building's new construction status and its active commissioning phase, TB2 served as an ideal site for our investigation. A crucial factor was the highly cooperative collaboration with the owner, who proactively supported the work from the outset. This personal interest and active participation were unique to TB2 and were not observed at the other testbeds T2 and TB1. As a result, the developed greening and irrigation systems could be approached in a holistic manner, aligned with circular economy principles, and monitored over several months. The data, empirical experience, and insights gained from the research and application at TB2 are of immense value to the overall SUA research project and to this dissertation, as they will be essential for the subsequent consolidation and

synthesis of data to identify system-compatible solutions and comparative analyses. The shop drawings in the Appendix B.2 provide detailed information about TestBed 2.

3.3 Tasks, Timeline and Operational Management

The official project period of the SUA research initiative was defined from 1 September 2022 to 31 August 2025 and was later extended without additional funding to 31 December 2025. The project comprised seventeen work packages and seven milestones (Figure 3.6), which were coordinated and refined over the course of the implementation. Within this timeline, the research team organised a range of activities, including academic conferences, stakeholder workshops, and a concluding symposium. Additionally, scientifically prepared surveys were conducted as part of the project's dissemination and stakeholder engagement strategy. Two of the work packages were dedicated exclusively to project and risk management, a structural legacy inherited from the initial funding proposal. In preparation for implementation, the team conducted an internal inquiry into which project management software (PMS) tools were most suitable and widely used within TU Dortmund. As an example the department of mechanical engineering and physics were contacted upfront to gather insights, and a comparison was made between Microsoft Project (MS Project), Factro, and Merlin Project. The feedback revealed substantial disparities between theoretical expectations, practical implementation and marketing related advertisement. MS Project was considered overly complex and time-consuming. Internal teams in academia reported difficulties in managing the software without assigning a dedicated staff member solely for its administration. The licensing model - charging per user on a monthly basis - expected budgetary challenges, as this cost had not been adequately projected in the original funding application. Reports of user frustration and inefficiencies overshadowed workflow continuity and quality standards (Kerzner, 2017; Lynch & Smith, 2021). In the case of Factro, a ticket-based PMS system highlighted that more time and cognitive effort were spent on the assignment and processing of task tickets than on the research work itself. This led to a reduction in research quality and increased strain on team members. Most project teams abandoned the use of MS Project and Factro after trial periods of up to six months due to physical exhaustion and performance losses (Schmidt & Zimmermann, 2022). For the SUA project, similar constraints emerged. After internal discussion, Merlin Project was selected as the most suitable and adjustable PMS due to its cross-functional capabilities and cost-effectiveness. It was intended to be managed by a single person and used across the team for tracking and coordination.

However, significant time investment was required to input and update project data in the initial phase. This effort was further impeded by incompatibility barriers through

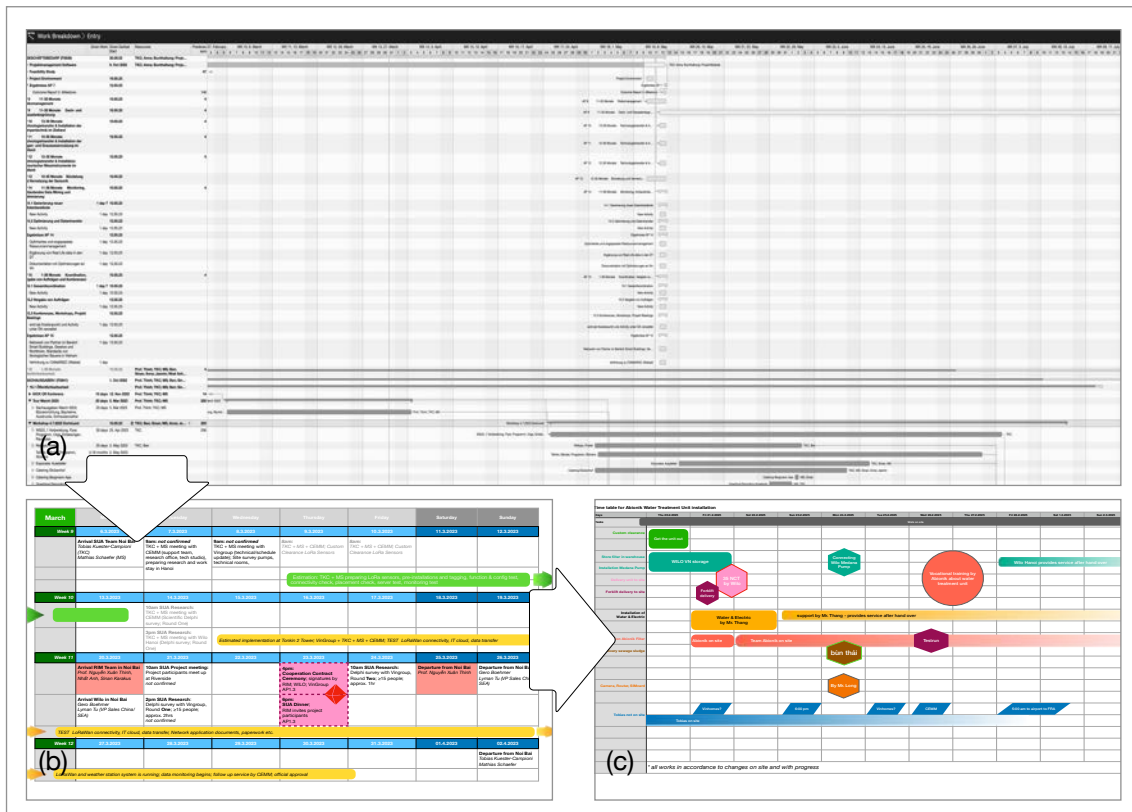


Figure 3.6: (a) Merlin Project Gantt, (b)+(c) Project Management Solution in Communication (schematic View of Simplification)

the internal SAP-based administrative system, which prevented direct integration of financial planning and expenditure reporting besides data interoperability. Another institutional hurdle concerned the use of third-party software on university-owned servers. Strict privacy and security protocols imposed by the university's IT center created barriers to installation especially in the case of sensor data gain and transfer onto the university's own server in the later stages. As the university's portable device was used both in Germany and on-site in Vietnam, recurring access restrictions impeded efficient project workflows. These constraints necessitated the use of a privately owned device, which, when connected via VPN, enabled faster and more stable access to the university's IT network from the outside rather than from the inside. A challenge that was also mentioned throughout the research of Hansen & Jaatun, 2020, for coordination and data synchronisation.

A further complexity, common to many international research projects, was the implementation of technologies and systems in real-world settings that had not previously been deployed in Vietnam. The rigidity of an overly formalised PMS environment requiring iterative engagement from all participants stood in contrast to the flexibility needed on-site. As a result, the project adopted a hybrid project management strategy during its first eighteen months using Merlin Project (Figure 3.6), which offers functionalities for Gantt charts, Kanban and mind maps along with cost

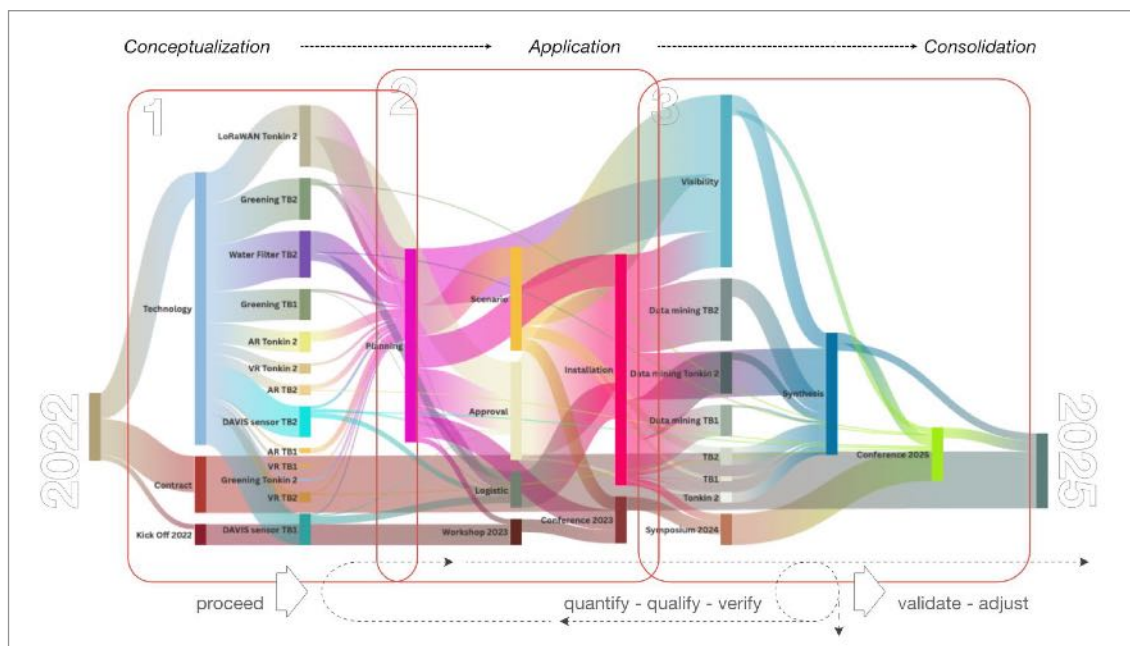


Figure 3.7: Task Flow within three Years of Project

estimation features. Due to the before mentioned interface conflict between the PMS, the servers and the administration system (SPS elements), cost tracking and expenditure reconciliation were even not possible. Consequently, the PMS was primarily used for scheduling work packages and tasks, such as conceptualisation, implementation, data collection, analysis, and transfer modeling. These tasks were often executed autonomously and in parallel. A ticket-based system instead would be antithetical to the holistic project approach, which requires the team to collaboratively seek cross-functional solutions. Such systems can constrain independent thought by fragmenting the workflow into isolated, single tasks. While this approach may increase individual accountability, it can hinder overall progress and lead to project delays, a finding observed by the project team in the academic environment itself. In order to effectively communicate with time parameters in both Germany and Vietnam, simplified schedules were graphically prepared to avoid foregrounding the complexity of the tasks (Figure 3.6 (a)-(c)). This simplification method also proved to be a helpful addition to the project workflow especially in Vietnam. Consequently, from an early stage, intensive graphical visualisations and scenarios were developed for both online and in-person meetings, which contributed essentially to the project's progress path. The Sankey diagram (Figure 3.7) visually represents the task flow over the three-year period, illustrating the complex and intertwined elements in a constant proceed to verification or cancelation. Three distinct phases can be identified in the diagram. The first is the conceptualisation phase, which focuses on the testing and configuration of the applied technologies. At the core lies the planning and simulation, approval, and implementation phase, marking a critical transition into system operation and data

collection in the second half of the project, which initiates the third phase of monitoring the adjusting and improving process. The final synthesis of results subsequently feeds into the transfer model, forming the basis for broader applicability and scalability. To provide a chronological framework for the project, one workshop, one symposium, and three conferences were strategically scheduled to present key project results and findings. In addition, the project team used these events to gather feedback from experts in the field by conducting online surveys (Ishikawa & Delphi). This approach provided the team with a baseline validation, ensuring the project's focus was correctly addressed and aligned with the expectations of the professional community.

3.4 Challenges and Limitations

Interdisciplinary and Cross-Cultural Collaboration:

The SUA research project and umbrella for this dissertation as a transnational initiative, faced typical hurdles common to interdisciplinary and intercultural collaborations from the outset. Initial differences in language, subject matter, and culture led to divergent expectations, interpretations, and understandings of the project's objectives and measures. This was particularly evident in the inconsistent use of the agreed-upon project language during meetings and in varied interpretations of technical terminology. Divergent role perceptions between academic research and practical implementation also posed obstacles: while the research team primarily sought cooperative knowledge exchange, the practical partners often focused on operational pressures, monetary efficiency, and adherence to sometimes rigid internal procedures. These differing priorities prompted a temporary adjustment of the project strategy, from a participatory orientation to a more application-driven approach. This did not signify a breakdown in collaboration but rather a strategic rebalancing that allowed for realistic goal achievement under the given conditions.

Communication and Operational Dynamics:

Another key challenge was the inconsistent communication flow. Despite clearly articulated goals in both the project proposal and verbal workshops, the transfer of knowledge was subject to fluctuations throughout the project. The physical distance between project sites meant that communication often lost momentum after the project partners returned to their home locations. Although the consortium recognises, that a continuous local presence was necessary for a project of this scale, this was not fully implemented due to budgetary constraints and a disadvantage for the first year. In day-to-day operations, frequent personnel changes and comprehension gaps in project execution repeatedly required constant coordination adjustments. Sustainable

information exchange was achieved only through the establishment of robust communication structures, using the locally common platform Zalo directly connected to the author of this work. A previously mentioned critical insight was the transformation to visual communication and highly condensed presentation of project information. For instance, video formats were limited to a maximum of two minutes to maintain attention and enhance comprehension. These experiences underscore the importance of adaptability, culturally sensitive communication, and iterative process design in complex project contexts.

Structural and Institutional Constraints:

The SUA project also exposed structural challenges in decision-making on all sides of the project partners. The TU Dortmund University is an educational institution, the German industry partner Wilo a global player and the local partner Vinhomes the biggest real-estate company in Vietnam. Decisions were either made rapidly or subjected to protracted processes involving multiple layers of internal checks and balances, moving from bottom to top and back again. A consistent willingness to innovate - combined with direct feedback - was observed among private, decentralised partners, particularly small and medium-sized enterprises (SMEs), which demonstrated greater engagement than participants from the public and institutional sectors. This observation provides valuable insights into potential success factors for future project constellations. A central challenge lay in balancing scientifically analytical requirements with practical feasibility. Reconciling research-driven recommendations with solution-oriented decision-making logics proved repeatedly complex. The findings underscored that existing institutional structures, hierarchical arrangements, and established decision-making mechanisms exert a decisive influence on project management. At times, institutional guidelines created ambiguity over where responsibility and decision-making authority resided. Moreover this dynamic, in certain phases, slowed the implementation of planned measures. Moreover, innovative concepts, particularly those with a holistic scope, tended to be assessed cautiously and integrated only incrementally into established operational procedures, existing reference frameworks, and published codes or regulations. As a result, smaller, well-defined pilot measures emerged as the more effective strategy for building long-term trust and laying the groundwork for wider adoption. The originally conceived systemic planning concept was therefore disaggregated into individual submodules to ensure compatibility with existing processes. In retrospect, this adjustment was regarded as a necessary intermediate step - one that fostered acceptance, created opportunities for joint learning, and kept the project aligned with its overarching trajectory.

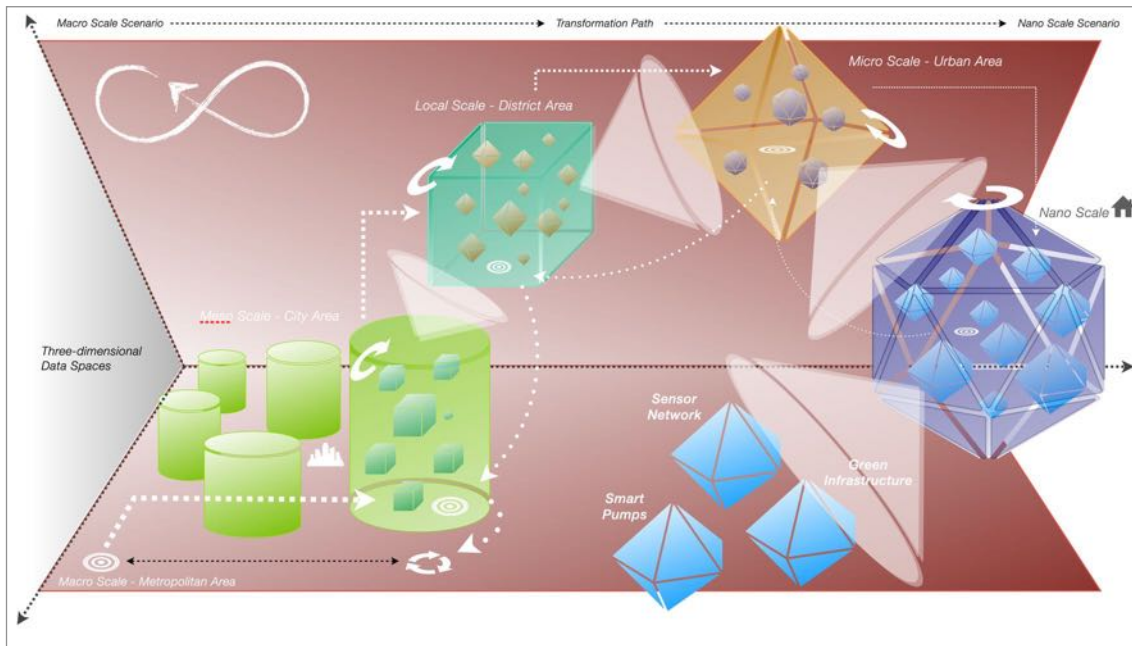


Figure 3.8: 3D Data Space within the Case Studies

Technical Challenges and Limitations:

The technical and material documentation provided for the case study buildings Tonkin 2 and TestBed 2, explicitly marked as as-built, was not always accurate. The conventional 2D plans, when translated into 3D formats, revealed deficiencies and construction discrepancies that necessitated on-site inspections and precise re-measurements to correct or to identify as built-in weaknesses, that supported the greater picture of optimisation potentials. Similar information gaps were encountered in technical building equipment planning that lacks information. In this context, the 3D models produced should be regarded as digital shadows - constructed retrospectively as uni-directional connection - rather than digital twins, which are designed from the beginning as foundational data-driven construct with bi-directional connection supporting real-time planning and implementation (Sepasgozar, 2021). Consumption datasets were largely unavailable from local partners, primarily due to privacy concerns and the absence of monitoring systems. Accordingly, systems were designed based on assumptions and only refined during operation, leading to schedule delays and

Limitations in accuracy:

A hybrid approach emerged: real-world construction was compared with empirical assumptions through scenario-based modeling, which closely approximated reality but required frequent revisions. This necessity for flexibility highlights the tension between practical adaptability and the scientific ideal of precision. The real laboratories that were established and managed during the project fostered bilateral

exchange of technological know-how and supported the cultivation of holistic systems thinking for resilient urban design. Additional limitations stem from foundational planning assumptions, such as understanding the building envelope as a thermal boundary, which plays a pivotal role in energy efficiency. Considering its impact on building energy demand, the design and material specification of envelope components remain central to sustainable performance (Evola & Lucchi, 2024).

Delimitation:

The diverse aspects examined in this study demand a high degree of complexity in merging the interdependencies of system-relevant concepts. The initial urban macro-level, along with its conceptual framework, is narrowed down to the nano-level with respect to the buildings under investigation. This level is visually understood as a three-dimensional data space (Figure 3.8), from which a scaling process back to the macro-level is to be performed. In the context of examining system solutions, the work fundamentally aims to establish an understanding of the interaction between building components and the bigger scale of a system that substitute urban resilience. Subsequently, through the integration of these findings into an urban area, a coupling to the Adaptive Node for high-rises in the Global South is feasible, scalable, still challengeable and in further extent adaptable to similar conditions. Technical able to continue such development stands in contrast to cultural limitations, interdisciplinary challenges and a general hesitation for integral system thinking into practice on the one side and constrains between distributing and manufacturing goals on the other.

4 Methodologies and Implementation

This chapter describes the methodologies with a primary focus on T2 and TB2, and includes a comparative material analysis referencing the T2 residential tower. Although the two buildings differ significantly in height and function, they share an identical structural system and construction method, making them suitable for direct comparison. The methodological section further elaborates on the applied strategies concerning the building itself and the associated implementation processes. Particular emphasis is placed on thermal monitoring, façade and rooftop greening, infrastructural enhancements, material usage, construction performance, and the implications for long-term durability and environmental resilience under the specific climatic and urban conditions of Hanoi.

4.1 Methodologies Overview

Between 2022 and 2025, methods and technologies were implemented across four distinct buildings in Hanoi: the Tonkin 2 (T2), TestBed 1 (TB1), TestBed 2 (TB2), and, towards the project's conclusion, TestBed 6 (TB6). The data generated from two of these sites were synthesised and integrated into a transfer model, which was designed to identify optimization potentials for developing smart urban districts.

Some of the technologies deployed were tested in Vietnam for the first time and therefore faces challenges. Their prototypical application under real-world conditions not only provided empirical evidence of their effectiveness but also enabled a context-specific evaluation within local climatic, infrastructural, and socioeconomic frameworks (Nguyen & Kim, 2020; UN-Habitat, 2022). The underlying holistic systems approach at the building level prompts a critical re-evaluation of conventional development paths. While still in an early stage of maturity, this approach shows substantial potential for scalability and transferability to high-density urban districts in metropolitan regions (Wong et al., 2021).

The schematic development diagram in Figure 4.1 illustrates the methodical scaling process. The initial concept was developed for the reference building, T2. The system was then scaled down and transferred to TB1, followed by its application in TB2 under more realistic conditions. Subsequently, insights gained from these testbeds were fed back into the original high-rise, creating an application-oriented cycle that allowed for a practical validation of the system solutions within existing buildings. This process simultaneously produced a representative cross-section of typical Vietnamese building typologies, serving as the basis for developing standardised building categories (Pham et al., 2023).

A comparative look at building classifications in Germany and Vietnam highlights fundamental differences in their systems, safety philosophies, and evaluation criteria.

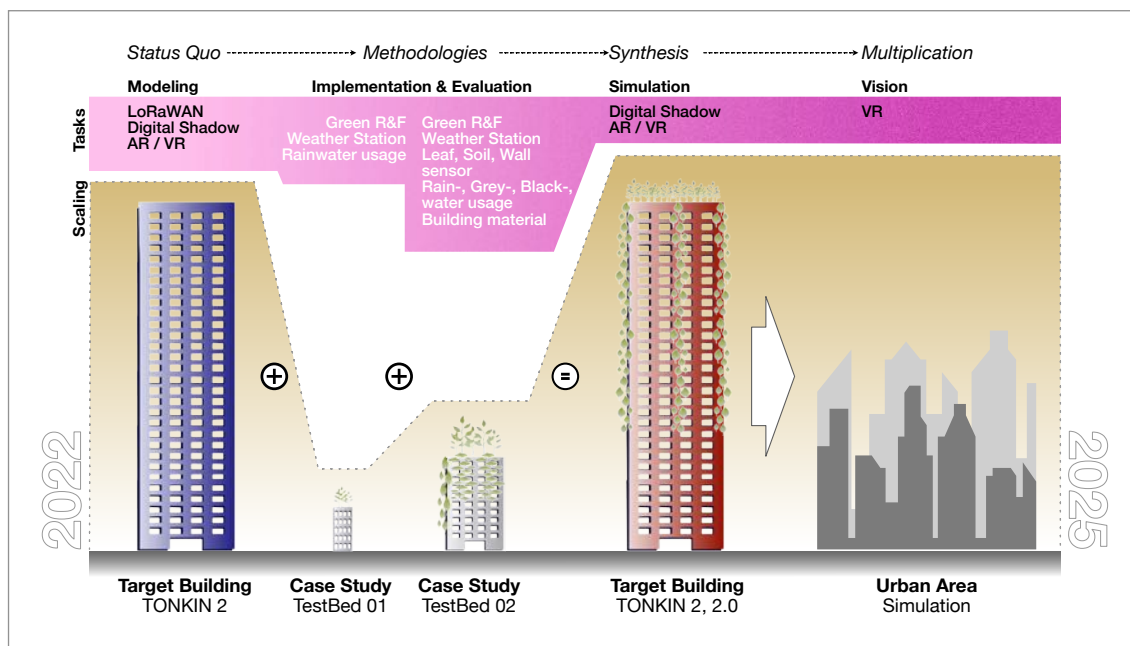


Figure 4.1: Project Scope of Scale

While the German Model Building Code (MBO, § 2, 2019) defines five building classes (GK I–V) primarily based on building height, usage units, and fire safety requirements, the Vietnamese classification system follows a more normative and function-based approach. The Vietnamese system classifies buildings predominantly according to QCVN 03:2012/BXD (technical standards) and QCVN 06:2020/BXD (fire safety standards). In addition, residential high-rises are categorised into classes A, B, and C based on their amenities, energy efficiency, fire protection, and infrastructural quality (Ministry of Construction, 2016; Phung & Nguyen, 2018). These divergent approaches are exemplified by the T2 building typology. In Germany, the building would be classified under GK V, while in Vietnam, it is assigned to Class A. A striking difference is seen in the installation of sprinkler systems: in Vietnamese Class A buildings, sprinklers are installed throughout, partly including in private apartments. In contrast, in Germany, the requirement for sprinklers begins above the high-rise limit of 22 meters and primarily focuses on corridors (public zone) and technical zones (BMI, 2020). Sprinkler systems within individual apartments are currently uncommon in Germany (Feuerwehrverband, 2022). In addition to technical related aspects, the SUA project utilised a range of other methods to support perspective-building and strategic orientation. These included a Delphi survey, visual time management tools, scenario planning, and digital modeling (Linstone & Turoff, 2002; Shenhar & Dvir, 2007). These methods were combined with practical field experiments on rainwater harvesting, building greening, and system development (Campiotti et al., 2022). In close coordination with project partners, these methods were adapted to local conditions and validated through an iterative process. This led to numerous situational

modifications in the methodological approach, a process consistent with the "move-and-proof" strategy common in local practice. By directly linking theory to practice, and in avoidance abstract complexity of system thinking and integration mentioned in chapter one, the project generated relevant solutions that now must prove their value in the built environment to be further developed into scalable technologies and to gain economic viability. Many of the procedures and findings developed are classified as applied research and development, with a clear interface to market entry. Following the initial three-year scientific research, development and adaptation phase, the next step, from an economic perspective, is a phase of monitoring and operational optimization. While this could not be fully completed within the funding period, the project's transfer to local stakeholders ensures its continuation.

4.2 Thermographic Imaging

4.2.1 Preconditions

Within the framework of the Smart Urban Areas (SUA) project, particular emphasis is placed on the paradigm shift regarding the treatment of high-rise buildings in the Global South, especially in relation to their integration within existing urban structures. Against this backdrop, it was considered essential to examine buildings of similar typology to the case study building T2 within the urban context of Hanoi, in order to gain a more nuanced understanding of the extent to which optimisation strategies related to energy efficiency and urban integration may be realistically implemented. A central question frequently arises as to whether high-rise buildings can be reinterpreted - both in planning and functionality - beyond their standardised normative use value.

In parallel with the implementation of the greening system at TB2, thermographic imaging was conducted between 7 and 10 August 2025 on the case study building itself as well as on T1, T2, and other structurally comparable buildings within the urban fabric of Hanoi. The measurements were carried out using a mobile thermal imaging camera. The selection of this specific time window was based on prior studies indicating that the highest concentration of extreme heat days in Hanoi occurs during the month of August. Furthermore, the weather stations and environmental sensors installed at TB1 and TB2 recorded the highest outdoor temperatures of the entire monitoring period during this week. For the purpose of data evaluation, 10 August 2025 was selected as the primary reference date, as it marked the peak ambient temperature within the measurement campaign.

4.2.2 Thermal Imaging Camera

To ensure accurate thermal measurements under urban field conditions, the selection and technical specification of the thermal imaging device used in this study are of critical importance. The device employed was the FLIR ONE PRO¹⁷ (iOS version), a high-resolution, mobile thermal imaging camera that connects directly to a smartphone via a Lightning interface. In this case, it was used in combination with an iPhone 13 mini.

The camera is equipped with a Lepton 3.5 microbolometer sensor, an uncooled infrared detector with a native thermal resolution of 160×120 pixels. FLIR's proprietary image enhancement technology, VividIR™, digitally interpolates this resolution up to 320×240 pixels, significantly improving image detail and edge detection. The sensor captures long-wave infrared radiation in the spectral range of 8 to 14 micrometers and offers a thermal sensitivity of approximately 70 Millikelvin. The frame rate is below 9 Hz, consistent with export regulations for mobile thermal imaging devices.

To enhance image clarity, the device incorporates a VGA visible-light camera (640×480 pixels). Its edge information is overlaid on the thermal image using MSX® (Multi-Spectral Dynamic Imaging) technology, enabling improved interpretation of structural features such as window frames and building edges.

The FLIR ONE PRO allows temperature measurements in a range from approximately $-20 \text{ }^\circ\text{C}$ to $+400 \text{ }^\circ\text{C}$, with an accuracy of $\pm 3 \text{ }^\circ\text{C}$ or $\pm 5\%$ of the measured value, depending on ambient conditions. While sub-zero temperatures do not occur in Hanoi, extreme summer temperatures combined with high humidity levels are typical. The measurement is based on a spot metering system, which can be expanded to up to three measurement points via the accompanying app.

Data were recorded and analysed using the FLIR ONE App, available for download via the App Store. The app offers live image display, still image and video recording, and the export of thermal data in JPG or MP4 format. For this study, the JPG format was primarily used, which presents a combined overlay of the thermal image and the corresponding visual contours. Despite its advanced functionality, the device remains compact, with dimensions of approximately $68 \times 34 \times 14$ mm and a weight of 42.8 grams. This made it especially suitable for mobile use across multiple measurement points in dense urban areas using a mobile phone. The manufacturer specifies an operational temperature range of $0 \text{ }^\circ\text{C}$ to $35 \text{ }^\circ\text{C}$.

However, during field measurements in Hanoi—where ambient temperatures reached up to $45 \text{ }^\circ\text{C}$ —the device developed significant internal heat. As a result, the battery

¹⁷ <https://www.flir.de/products/flir-one-pro/?vertical=condition+monitoring&segment=solutions> (15.6.2024)

runtime was reduced to approximately 15 minutes, and occasional connectivity issues with the mobile device were observed. These were resolved by temporarily switching off and allowing the device to cool before resuming operation. The validation of the recorded surface temperature distributions, simulation data generated using ENVI-met (Schaefer et al., 2025) were selectively referenced. These served as a qualitative cross-check and confirmed that, under methodologically controlled conditions, the thermal camera is capable of producing reliable reference values for thermographic urban analysis.

The thermal imaging sessions were conducted during predefined time windows - in the morning (06:00 - 07:00), midday (13:00 - 14:00), and evening (18:00 - 19:00) - while accounting for time-dependent variations in traffic density. As expected, the highest surface temperatures were recorded during the midday interval between 13:00 and 14:00.

4.2.3 Thermal Imaging to Building Surfaces

On 7 and 8 August 2024, thermal imaging was conducted on urban structures in the Greater Hanoi area, including high-rise facades in NUAs and developments (Appendix A). These recordings can be considered reference data, as they were taken during the period of highest solar heat exposure within those days. The eastern facades were photographed at approximately 10:00 local time, and the western facades at around 16:00 in the afternoon, coinciding with the periods of maximum solar radiation on materials and surfaces in Vietnam. As most measurements were taken at pedestrian eye level, the viewing angle changes with increasing building height. Deviations within the normal range of ± 1 °C are considered acceptable. Surface temperatures between 30 °C and 90 °C were recorded, depending on the surface material. Residential high-rises are generally finished with cement plaster, whereas office buildings are more commonly constructed with aluminium glass curtain walls.

A large proportion of roofs, particularly on private buildings, for instance the traditional tube buildings in Hanoi, are covered or shaded with sheet metal. In Vietnam, sheet metal roofing in red, green, or blue is most commonly used. This surface material reaches the highest recorded heat temperatures but also cools down relatively quickly. Nevertheless, it continues to emit heat into the surrounding air, thereby increasing the risk of heat islands and heat stress. Figure 4.2 illustrates thermal images with a spectrum of typical surface temperatures on days of intense heat exposure and solar radiation. The images were taken on 5 July 2024 and on 3 August 2024 between 13:00 and 17:00 around TestBed 2 just before and after greening the roof. Thermal imaging are used as accurate measurement of surface dynamics and general understanding.

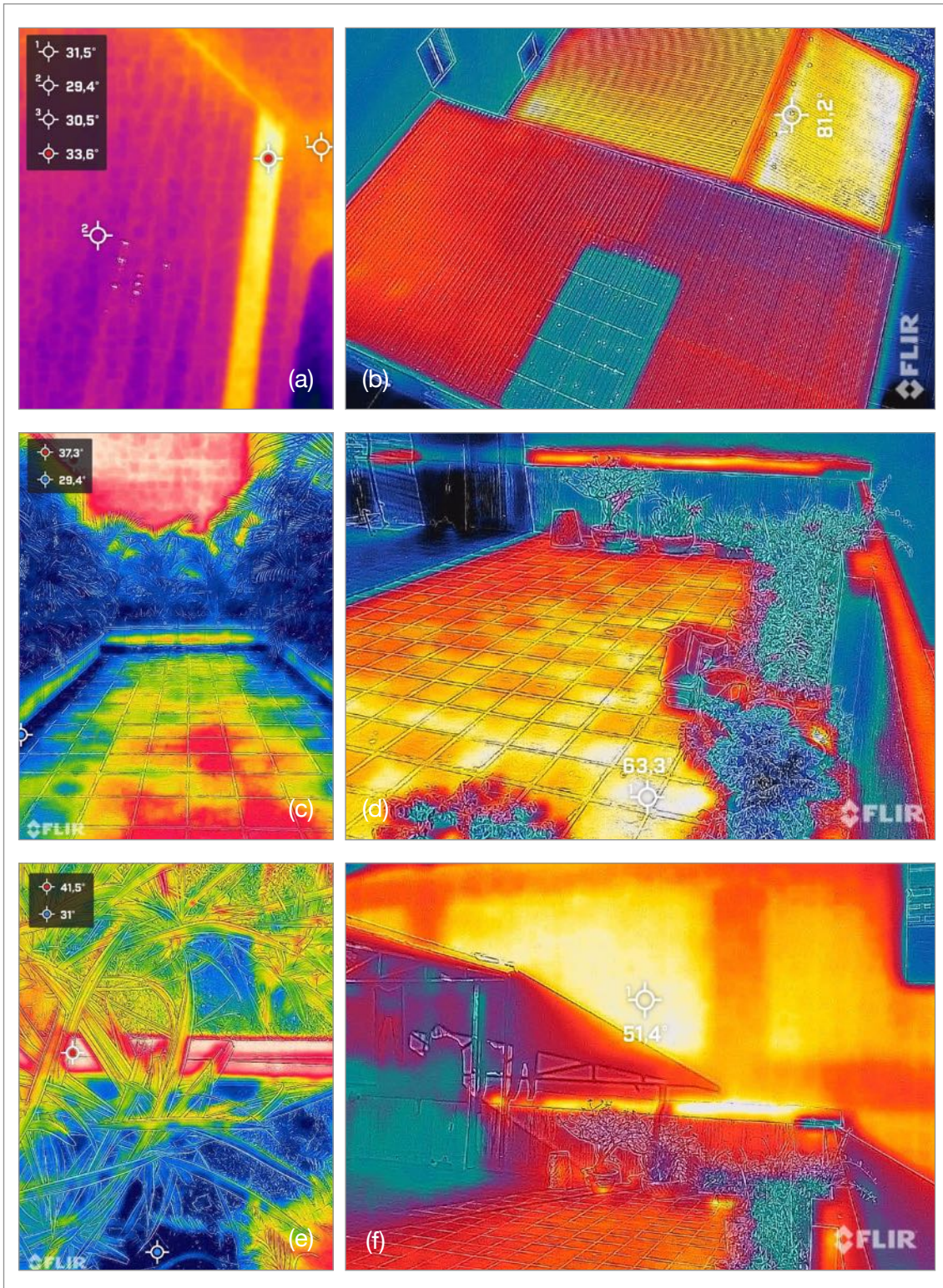


Figure 4.2: (a) Window Frame from Inside, (b) Sheet Metal Roof grey, (c) Roof Top after Greening, (d) Roof Top before Greening, (e) Detail of Plants and Construction, (f) Surface Temperature of West Wall to East Neighbour

4.3 Empirical Building Envelope Parameters

4.3.1 Building Organism

This chapter questioning the specific methodology of building and material analysis, using the residential high-rise building T2 as primary reference cases for investigation about the building envelope's system.

Although differing significantly in height and function, both buildings share an identical structural typology that reflects the current standard in multi-storey construction in Hanoi. Both structures are based on reinforced concrete frame systems with down-stand beams, with walls inserted between floor slabs to enclose the building and provide climatic protection. This structural consistency allows for a comparative analysis of materiality and construction detailing, as well as implications for long-term performance under tropical urban conditions.

A central component of the methodological approach is the comparison of design and construction practices with national and voluntary standards. The analysis references:

- QCVN 09:2017/BXD – National Technical Regulation on Energy Efficiency in Buildings, a binding baseline for sustainable construction in Vietnam.
- LOTUS NC V3, a voluntary green building rating system published by the Vietnam Green Building Council (VGBC). While non-mandatory, it serves as an additional comparative benchmark for sustainable construction practices.

To systematically assess material choices, implementation quality, and construction the analysis relies on digital building models. These were developed using ArchiCAD, a BIM software platform common in Vietnam alongside Autodesk Revit. ArchiCAD was selected due to its integrated BIMx environment for Augmented Reality (AR) visualisation, and its compatibility with Twinmotion (TM) and Unreal Engine (UE) for immersive virtual simulation. Existing user expertise further justified the choice of platform, enabling a more time-efficient and technically precise modeling process.

Supporting the increasing recognition of high-rise buildings as urban organisms (Figure 4.3), the analysis places particular emphasis on the building envelope, understood as a protective interface similar to the human skin. The investigation is guided by a biomimetic framework, structured around the following analogies:

- Skin Building Envelope
- Brain Building Management System
- Bones Structural Framework
- Vascular System Building Infrastructure (with a focus on water cycle)
- Respiratory System Building Ventilation

The conceptual approach supports a holistic understanding of building performance in a rapidly urbanising, tropical context.

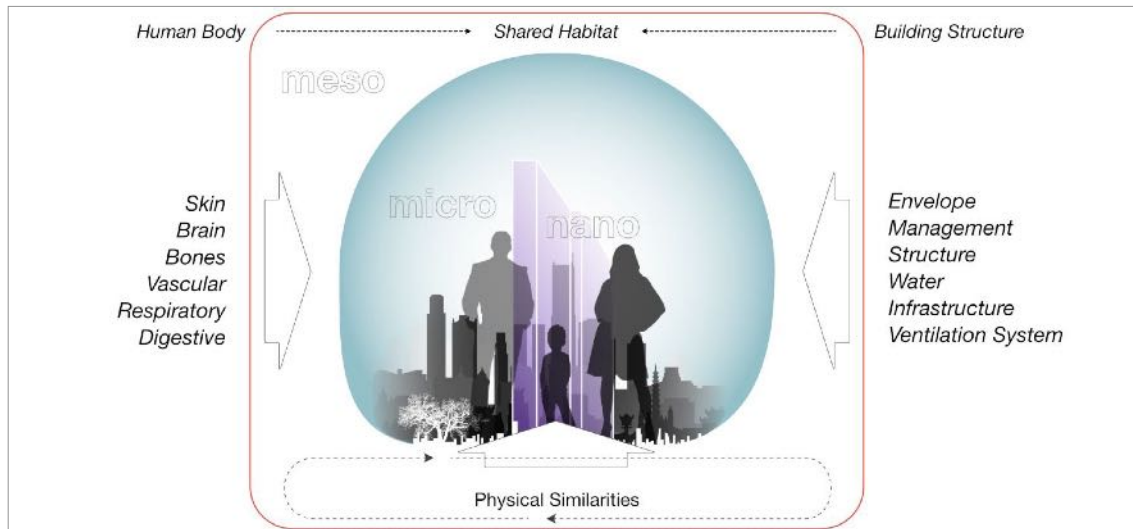


Figure 4.3: Building Organism System

As part of the material analysis, metrics such as the Wall-to-Window Ratio (WWR) are evaluated for their thermal impact. Commonly used wall and façade materials in the Vietnamese building construction market are examined in terms of performance and environmental suitability in the Brick-to-Concrete ratio (BCR). The investigation further addresses optimization potential in concrete slab construction techniques, comparative weight assessments for mechanical equipment, and the integration of green infrastructure systems in a separate chapter. Reference data from TB2 is used as a calibration point to validate building mass, vegetation load, and structural constraints and applied on Tonkin 2.

4.3.2 Wall to Window Ratio

Based on the available technical documentation, both Tonkin residential towers 1 and 2 were digitally modelled in 3D using the aforementioned BIM software. In addition to representing the building structure and construction elements, the initial step focused on understanding the wall-to-window ratio (WWR), which provides preliminary insights into façade performance. The percentage ratio is externally visible and was examined and calculated for this purpose. Large openings within the punctuated façade of a high-rise building proof high levels of daylight penetration into the interior, and they indicate the potential for rapid indoor heat gain due to solar radiation. This raises the question of the material quality of both the wall and the window elements.

On-site observations, consistent with many typical high-rise buildings in sub tropical Hanoi, not only the Tonkin towers, revealed regular and large-scale fenestration, often covered from the inside with curtains. In such cases, the principle of healthy daylight provision is effectively abandoned. Two primary factors contribute to this:

1. Curtains are kept closed for reasons of privacy.

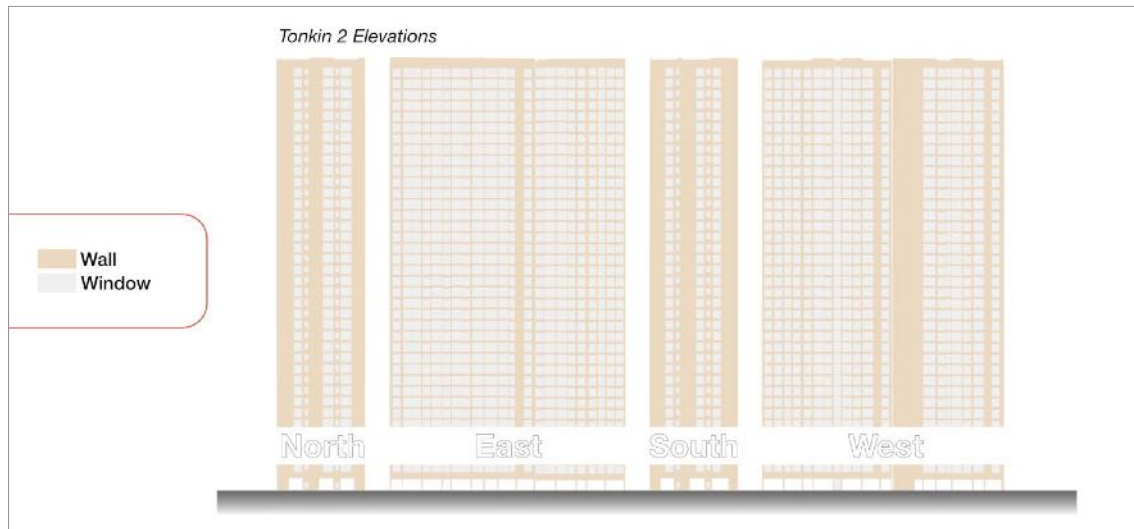


Figure 4.4: Tonkin 2, Wall-to-Window Ratio (WWR)

2. Curtains are kept closed due to excessive solar heat gain.

Large glazed areas are an important factor in the pre-sale marketing of apartments and play a significant role in the real estate developers' promotional strategies. In contrast, questions of energy performance and the functional appropriateness of the installed wall materials are of secondary importance. In the case of Tonkin towers 1 and 2, achieving a uniform visual appearance and replicating the building type took precedence. At present, 26 buildings of this type have been constructed within Vinhomes Smart City Hanoi. A doubled variant of this building type exists or is under construction in 15 additional cases. Various other building types, including L-shaped and semi-circular configurations, are also present, resulting in a total of 50 high-rise buildings, each with an average of at least 38 floors. The Tonkin 2 tower has 39 floors and is finished with a white grid pattern applied to the rendered façade. The infill areas within the grid are highlighted in anthracite and grey-beige tones. At the base, the lower three floors are clad in dark brown textured render. The ground floor accommodates a lobby, communal spaces, retail units, as well as vertical circulation cores and emergency exits. Both Tonkin towers 1 and 2 are positioned above a basement used as a car park and for technical service rooms. For the purposes of determining the WWR, the external façade area from the ground floor up to the attic level of the roof top was considered (Figure 4.4). The wall-to-window ratio was calculated as shown in Table 4.1, based on wall surfaces that facing direct sun light and containing windows. The total WWR must not be misinterpreted, as it generally reflects a higher proportion of wall area. The values for the east and west façades are critical in determining the thermal gain of the building mass and, consequently, the façade's performance quality. Furthermore, measurements through simulation revealed that the north façade is affected by unexpected solar heat gain.

Table 4.1: Tonkin 2, Wall-to-Window Ratio (WWR)

WWR	Total (m²)	Wall (m²)	Window (m²)	Ratio (%/%)
North	3.650,467	2.550,159	1.100,308	70/30
East	10.305,723	4.082,777	6.235,019	40/60
South	3.648,889	2.731,606	917,283	75/25
West	9.960,798	5.184,593	4.776,205	52/48
WWR total	27.565,877	14.549,135	13.028,815	59/41

4.3.3 Brick to Concrete Ratio

The subsequent stage of the investigation focused on determining the brick-to-concrete ratio (BCR), which corresponds to the masonry-to-framework ratio. The Tonkin 2 residential tower is constructed using conventional methods: a reinforced concrete frame, comprising columns, floor slabs, and supporting beams, is infilled with traditionally fired clay bricks. These infill walls occupy the vertical openings within the concrete framework, providing protection against climatic influences, but are non-load-bearing.

Two-hole standard bricks with nominal dimensions of 210 × 100 × 57 mm are laid in a single layer and coated on both sides with cement render. The cement render exhibits greater hardness than the masonry units. Both render and mortar are mixed and applied on-site, a process that introduces additional moisture into the construction; however, this aspect is not part of the present investigation. The average mass of a single two-hole brick is approximately 1.3 kg. For one square meter of exterior wall, 56.5 bricks are required, assuming a 18-20 mm mortar joint thickness. This construction method remains dominant in the local building industry despite the availability - over the past decade - of more advanced masonry materials, such as autoclaved aerated concrete (AAC), which have only gradually gained momentum and market acceptance. Notably, this persistence can be linked to historical patterns in urban morphology: in traditional districts of Hanoi, narrow alleys limited material delivery to small vehicles. By contrast, contemporary urban developments are large in scale, with delivery now handled by trucks carrying loads of 20-30 metric tonnes, allowing for more flexible material logistics.

Due to dimensional tolerances related to local brick manufacturing, internal plaster thickness averages approximately 15 mm, while exterior plaster can reach 35 mm or more to compensate for misalignments between masonry and concrete frame. Consequently, an overall exterior wall thickness of 150 mm - consistent with the original design documentation - is adopted for calculation purposes.



Figure 4.5: Tonkin 2, Brick-to-Concrete Ratio (BCR)

Using the digital 3D building model, construction elements were classified and visually differentiated, enabling quantification of the brick-to-concrete ratio (Figure 4.5). The BCR was calculated as shown in Table 4.2, based on the total external envelope area (including wall surfaces in emergency exit zones) and excluding window openings. The overall BCR of 44/56 shows a dominance of concrete material in the overall facade surface.

4.3.4 Brick Wall Conditions

In the following step, one square metre of the existing exterior brick wall of the building is examined, as this material currently presents the greatest system-relevant potential for optimisation. It also helps to get a comprehensive picture about the brick-to-wall conditions (BWC). As part of the building envelope - the “skin” of the structure - the wall is exposed to the highest fluctuations in solar radiation and is intended to protect the interior apartments from thermal and climatic impacts. Furthermore, the exterior façade contributes significantly to the building’s overarching system and exerts considerable influence on its performance. For this reason, the wall merits close analysis, particularly with a view to assessing potential resilience characteristics at the conclusion of the study. For comparative purposes, the Vietnamese building code QCVN 09:2017/BXD is referenced alongside datasets from local suppliers. Evidence of thermal bridging is inherent in the wall construction method, which is commonly observed throughout Vietnam. In the south of the country, a wider range of brick formats are available, such as six-hole bricks with improved thermal transmittance values, yet it is notable that the uppermost line of the masonry shell between reinforced concrete slabs is invariably laid with diagonally positioned bricks (Figure

Table 4.2: Tonkin 2, Brick-to-Concrete Ratio (BCR)

BCR	Wall (m ²)	Brick (m ²)	Concrete (m ²)	Ratio (%/%)
North	5.009,418	1.603,504	3.699,673	32/68
East	5.584,737	3.314,991	2.269,746	59/41
South	5.453,771	1.713,628	3.740,143	31/69
West	5.889,609	3.164,275	2.725,334	54/46
BCR total	21.937,535	9.796,398	12.434,896	44/56

4.6). Questions concerning the technical specifications or construction pace advantages of this practice could not be answered consistently. From a building physics perspective, however, this detail is of significance when solar heat gains are transmitted through the wall. This construction detail also illustrates that the walls are non-load-bearing elements, positioned between slabs solely to enclose the building envelope against weather without further physical obstacles.

The definition of one square meter of the exterior envelope for this break down analysis is: 35 mm exterior cement render (plaster), 100 mm single-layer brickwork, and 15 mm interior cement render. In addition to calculating the number of bricks used, the analysis includes mortar and cement plaster quantities, total weight and construction cost besides time. Detailed Table 4.3 summarises the specific values per square meter as-built based on measurements taken on site and compared with the National Technical Regulation on Energy Efficiency in Buildings QCVN 09:2017/BXD, and the relevant EN ISO 6946:2007 standard.

Thermal Conductivity in accordance with EN ISO 6946:2007:

$$U = \frac{1}{R_{si} + \sum_{i=1}^n \frac{d_i}{\lambda_i} + R_{se}}$$

U	= Thermal transmittance [W/(m ² ·K)]
R _{si}	= Internal surface resistance [m ² ·K/W]
R _{se}	= External surface resistance [m ² ·K/W]
d _i	= Thickness of layer <i>i</i> [m]
λ _i	= Thermal conductivity of layer <i>i</i> [W/(mK)]
n	= Number of layers in the wall assembly



Figure 4.6: (a) Concrete-Brick Wall, (b) Wall-Slab/Beam Transition, (c) AAC Walls

For the layer resistance following equation was taken:

$$R_{\text{total}} = R_{si} + \sum_{i=1}^n \frac{d_i}{\lambda_i} + R_{se}$$

For the masonry layer (brick + mortar), an effective thermal conductivity (λ_{eff}) was calculated as a volume-weighted value:

$$\lambda_{\text{eff}} = f_{\text{brick}} \cdot \lambda_{\text{brick}} + f_{\text{mortar}} \cdot \lambda_{\text{mortar}}$$

$$\begin{aligned} f_{\text{brick}} &= 0.6763 \\ \lambda_{\text{brick}} &= 0.52 \text{ W/mK} \\ f_{\text{mortar}} &= 0.3237 \\ \lambda_{\text{mortar}} &= 0.93 \text{ W/mK} \\ \lambda_{\text{eff}} &= 0.652717 \end{aligned}$$

Table 4.3: Tonkin 2, exterior Brick-to-Wall Condition (BWC) (as built) of one Square Meter

Item	Parameters	Unit	Source
Wall specifications			
Material	Clay		On site
Hollow brick dimension	210 x 100 x 57	mm	On site; TCVN 1450-1998

Item	Parameters	Unit	Source
Cement mortar (bed/head)	20	mm	On site
Exterior cement render	35	mm	On site
Interior cement render	15	mm	On site
Thermal air gap	-	-	Missing
Total wall thickness	150	mm	On site
Quantities & Weights			
Brick count	56,50	Pcs/m ²	On site
Unit mass	1,30	Kg/pc	Material sample
Brick mass	73,45	Kg/m ²	Calculation
Cement-sand mortar	1.800	Kg/m ³	QCVN 09:2017/BXD
Mortar mass	58,27	Kg/m ²	Calculation
Cement plaster	1.600	Kg/m ³	QCVN 09:2017/BXD
Exterior plaster	56	Kg/m ²	Calculation
Interior plaster	24	Kg/m ²	Calculation
Mass plaster	80	Kg/m ²	Calculation
Total wall weight	211,72	Kg/m²	Sum of calculation
Thermal condition			
Brick volume	0.06763	m ³	Calculation
Mortar volume	0.03237	m ³	Calculation
Gross masonry volume	0.10000	m ³	Calculation
Brick volume fraction	0.6763	-	Calculation
Mortar volume fraction	0.3237	-	Calculation
Plaster conductivity	0.93	W/mK	QCVN 09:2017/BXD
Mortar conductivity	0.93	W/mK	QCVN 09:2017/BXD
Brick conductivity	0.52	W/mK	QCVN 09:2017/BXD
Int. surface resistance R _{si}	0.13	-	EN ISO 6946:2007
Ext. surface resistance R _{se}	0.04	-	EN ISO 6946:2007

Item	Parameters	Unit	Source		
Thermal R-Value	0.3769	m ² ·K/W	EN ISO 6946:2007		
Thermal U-Value	2.65	W/m ² ·K	EN ISO 6946:2007		
Prices (dry mix)	Quantity (m ²)	Unit (VND)	m ² (VND)	Unit (USD)	m ² (USD)
Bricks (Pos.12)	56,50	3.500	197.750	0,41	7,91
Brick mortar (25kg/bag)	2,33	22.500	52.425	0,90	2,10
Exterior plaster (25kg/bag)	2,24	350.000	784.000	14,00	31,96
Interior plaster (25kg/bag)	0,96	500.000	480.000	20,00	19,20
Water (Liter)	20,00	10,00	200,00	0,00	0,01
		₫	1.514.375	US\$	61,17
Construction time	Work (min)	Curing (min)			
Masonry (brick laying)	80	200			
Plaster (in 2 layers)	120	300			

4.3.5 Construction Framework

Concrete, particularly reinforced concrete, remains one of the principal building materials in contemporary construction. As the primary structural system for many high-rise buildings worldwide, concrete frameworks form the fundamental load-bearing skeleton. By providing substantial usable space on a relatively small footprint, high-rise buildings accommodate diverse urban functions. In city centers where land prices are high, vertical development becomes the logical approach, with maximum height limited primarily by factors such as airport flight paths, as seen in several cities of the Global South.

The construction industry is responsible for approximately 40 % of global CO₂ emissions, with Portland cement and concrete production being major contributors (Scrivener et al., 2018). The largest concentration of current megacities lies between latitudes 30° N and 30° S, with future growth expected to cluster particularly in the Middle East and Southeast Asia^{18,19}.

¹⁸ <https://www.oxfordeconomics.com/resource/rise-of-new-megacities-will-drive-global-urban-growth/> (18.12.2024)

¹⁹ <https://population.un.org/wup/maps?tab=Percentage%20Urban%20by%20Size%20Class&year=2030> (12.08.2024)

Table 4.4: Tonkin 2 Construction Framework Elements

Construction Elements	Volume concrete (m³)	Weight concrete (t)	CO₂e/m³ Manu (t)	CO₂e/m³ Trans (t)
Downstand beam 290×300 mm (outside)	799,457	1.918,697	334,173	7,675
Downstand beam 290×200 mm (inside)	461,936	1.108,646	193,089	4,435
Core 3.24 m (without 160 mm slab)	1.009,584	2.423,002	422,006	9,692
Core 5.34 m (without 160 mm slab)	43,788	105,091	18,303	0,420
Slab (thickness 160 mm)	7.678,445	18.428,268	3.209,590	73,713
Columns 2.950 m floors 2–38 (50 pcs/floor)	5.507,709	13.218,502	2.302,222	52,874
Columns 5.050 m floor 1 (50 pcs/floor)	254,823	611,575	106,516	2,446
Total	15.755,742	37.813,781	6.585,900	151,255
Cradle-to-gate CO ₂ e/m ³			6.737,155	

In Vietnam, rapid urbanisation and large-scale infrastructure development have driven a sustained increase in demand for concrete. These conditions highlight the importance of identifying optimisation potential within the structural design of the Tonkin 2 residential tower. The project employs a reinforced concrete frame with down-stand beams, a prototypical design approach currently used by Vinhomes in many large-scale developments across the country.

The scalability of the findings is a priority, alongside improving material efficiency, reducing CO₂ emissions (Cheng et al., 2023), and enhancing construction quality. Emerging techniques such as modular and prefabricated construction, optimised concrete spacers, and the integration of cross-laminated timber (CLT) elements present opportunities to reduce material consumption, improve structural performance, expand usable floor area, and open new market applications. This study focuses specifically on the floor slabs of the Tonkin 2 construction framework (CF) above ground, as they present tangible potential for material savings. Table 4.4

summarises the overall assumptions for the building's total concrete volume and CO₂ emissions.

Manufacturing emissions were evaluated by the equation down below:

$$E_{\text{mfg}} (\text{t CO}_2\text{e}) = V (\text{m}^3) \times 0.35 \left(\frac{\text{t CO}_2\text{e}}{\text{m}^3} \right)$$

V = concrete volume in m³

0,418 = emission factor conventional concrete (Gomes et al., 2019) CO₂e/m³

The calculation for transport emissions per cubic meter is based on the truck's payload and the emission factor. A standard truck with a volume of 10 m³ has a payload of approximately 24 tonnes. This results in a material density of 2.4 t/m³. Using a well-to-wheel emission factor of 80 g CO₂e per tonne-km, the specific emission per cubic meter of transported material can be calculated:

The density of 2.4 t/m³ is multiplied by the emission factor (2.4 t/m³ × 80 g CO₂e/[t·km]), which yields a value of 192 g CO₂e per m³-km. This means that for every cubic meter of material transported for one Kilometer, 192 grams of CO₂ equivalent are emitted.

$$E_{\text{tx}} (\text{kg CO}_2\text{e m}^{-3}) = 0.08 \rho_{\text{conc}} (\text{t m}^{-3}) d_{\text{rt}} (\text{km})$$

ρ_{conc} = 2.400kg/m³ (2.4t/m³)

d_{rt} = 50 km → ~9.6kg/m³ (0.0096 t/m³) (average laden)²⁰

The equation with parameters and units included used:

$$E_{\text{total}} (\text{t CO}_2\text{e}) = V (\text{m}^3) \times (0.418 + 0.0096) (\text{t m}^{-3})$$

The integration of Supplementary Cementitious Materials (SCMs²¹), such as fly ash and slag, has become a central focus of scientific and industrial efforts to provide the cement sector with economically viable solutions for reducing its carbon footprint while simultaneously enhancing the performance and durability of concrete. These

²⁰ Emissions for vehicles and goods: <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023> (12.08.2025)

²¹ Supplementary Cementitious Materials (CMS): <https://jst-ud.vn/jst-ud/article/download/8762/6058/18817> (12.08.2025)

materials contribute to the long-term strength development of the cementitious matrix through pozzolanic and/or hydraulic reactions, as substantiated by extensive research (Scrivener et al., 2018; Azad et al., 2021). The resulting refined microstructure is crucial for significantly reducing permeability, thereby improving durability and resistance to aggressive agents like chlorides and sulphates. Furthermore, SCMs enhance the workability of fresh concrete, which facilitates placement and pumping. A key advantage is also the reduction of the heat of hydration, which inhibits the risk of thermal cracking in large-scale structural elements. This approach, to a certain extent, mirrors the principal method of *opus caementicium* (Roman concrete), which utilised naturally occurring volcanic ash as a pozzolan rather than industrial byproducts.

4.3.6 Virtual Modeling as Instrument

The application of virtual models constituted an essential methodological component of the SUA project and of this study. The objective was both to enhance the understanding of the investigated buildings and to establish a basis for partial evaluation besides embedding information of the virtual model into the project website.

The starting point consisted of the available as-built documentation, which in the case of the Tonkin 2 tower and TestBeds 01, 02, and 06 proved to be incomplete, erroneous, or entirely absent. While the plans for Tonkin 2 and TestBed 2 did not reflect the realised “as-built” condition, no documentation was available for TestBeds 01 and 06. In all cases, supplementary field surveys, sketches, and control measurements were required to verify missing or inaccurate information and to generate digital models. In this way, a data foundation was established that adequately represented the actual built condition for investigations.

The CAD modeling was carried out in ArchiCAD. The three-dimensional building models enabled precise visualisation of spatial relationships and technical interfaces. Furthermore, during the transfer of two-dimensional black white plans into a 3D context, planning inconsistencies such as axis offsets or unclear shaft positions could already be identified. Communication with local partners, however, proved problematic, as technical queries were not addressed directly but channelled through intermediaries or left unanswered.

The models developed in this study are best classified as digital shadows: retrospective, one-directional reconstructions of built conditions. By contrast, digital twins are conceived from the outset as bi-directional, data-driven environments supporting real-time planning and implementation. Within the SUA project, digital shadows were applied as analytical tools, supplemented by virtual modeling for communication and scenario testing. Although these do not provide complete

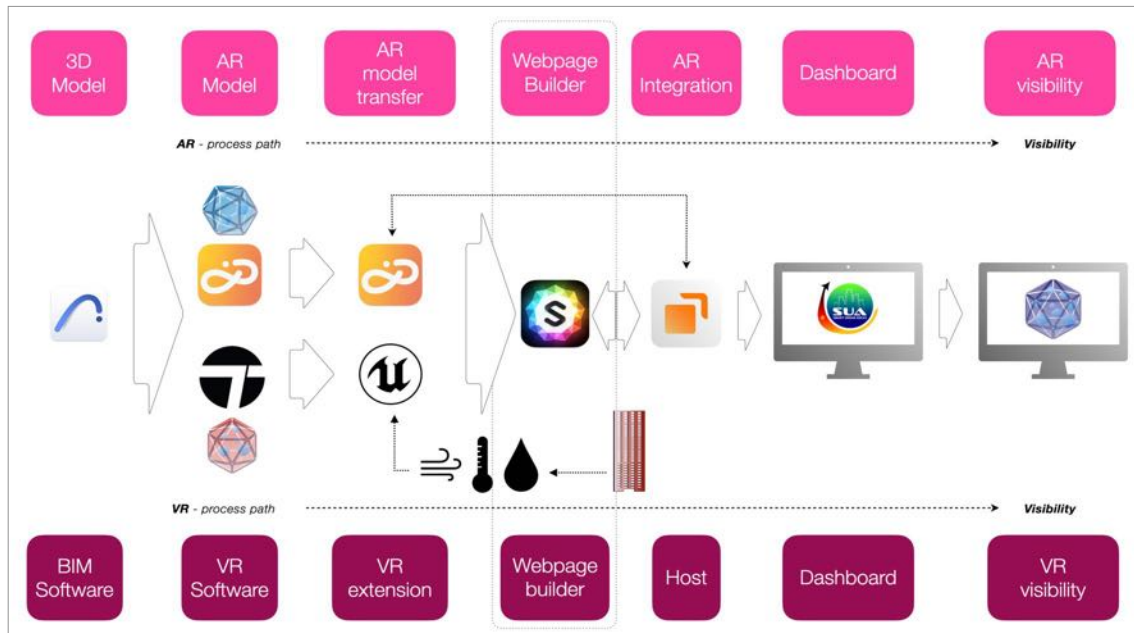


Figure 4.7: Augmented Reality (AR) and Virtual Reality (VR) Visualisation Process

documentation, they proved sufficient for the purposes of simulation and visualisation in a research context. The models were exported to BIMx for use in interactive presentations during technical meetings and interdisciplinary communication. In addition, models were transferred to Twinmotion to generate immersive virtual reality (VR) scenarios. Within the SUA research team, further attempts were made to embed the models in a GIS environment using Unreal Engine and to link them with real-time data. This approach, however, failed due to software compatibility issues and data restrictions spanning two countries and third parties.

In parallel, experimental efforts were undertaken to integrate real-time climate data into the ArchiCAD models and to make these outputs visible via BIMx on the project website. The website itself was developed in Sparkle, which enabled the embedding of the models through an HTML widget, allowing external users to access the virtual environments. In the longer term, the intention was to develop a web-based dashboard displaying the test fields and buildings in real time. However, this implementation encountered significant challenges concerning interface interoperability, server-side data management, and compliance with data protection requirements. These experiences made clear at an early stage that both the construction industry and academia currently exploit the potential of BIM for simulation and adaptive scenario development only to a limited extent. Nevertheless, the creation and application of Digital Shadows within the SUA project demonstrate that even on this basic level a significant gain in knowledge can be achieved with regard to construction comprehension, communication, and research. Figure 4.7 illustrates the process flows of model visualisation. The upper sequence represents

Augmented Reality (AR): starting from the ArchiCAD model, the data are exported in BIMx format. Following storage in the BIMx Model Transfer Cloud, a hyperlink is generated and integrated into the HTML widget of the website builder. This procedure enables the online visualisation of the three-dimensional model including all AR functionalities. Hosting via the cloud environment ensures access across digital devices. A comparable sequence applies to Virtual Reality (VR): starting from the BIM model, a VR model is developed and exported via DirectLink. In this workflow, no inconsistencies were observed; realistic effects were specifically prepared for immersive presentation with a 3D headset. For scaling and the integration of real-time data, however, the VR model had to be transferred to Unreal Engine in .datasmith format, as a direct export from TwinMotion was not possible. From there, GIS functions could be incorporated. The LoRaWAN data of Tonkin 2 were linked to the building model via .csv format and prepared for display through the VR headset.

4.4 Field Study of Green System and Sensor Network

4.4.1 Planting Concept and Spatial Organisation

The roof area at case study TB2, totalling 103 m², is fully exposed to solar radiation and covered by red terracotta tiles with dimensions of 30 x 30 cm and a thickness of 4 cm, featuring a joint width of 1.5 cm. The perimeter parapet wall is rendered with cement plaster and finished in white paint. A freestanding metal structure with green-coated corrugated sheet metal provides cover for laundry facilities, natural laundry drying and protects the skylight for the daylight and ventilation shaft, which vertically connects the floors from the lobby in 1st floor and ensures natural air exchange.

Rainwater drainage, consisting of DN 90 mm piping, is facilitated by 1% slope of the flat roof towards East and West to a ground-level gutter located at the edge of the flooring, leading to floor drains and downpipes. Wastewater from washing machines is also discharged into these floor drains. According to the existing technical plans, the rainwater and wastewater lines are designed as separate systems. However, on-site investigations and construction measures revealed this to be incorrect; the rainwater pipe is connected to the grey water line in the basement area. Due to the structural freedom on the roof, the following arrangement could be implemented on the roof and facade:

The utilisation of native plant species is crucial for the sustainable implementation of greening, as they exhibit superior adaptation to tropical climate conditions compared to exotic succulents (Klein and Coffman, 2015). Following detailed prior planning, the

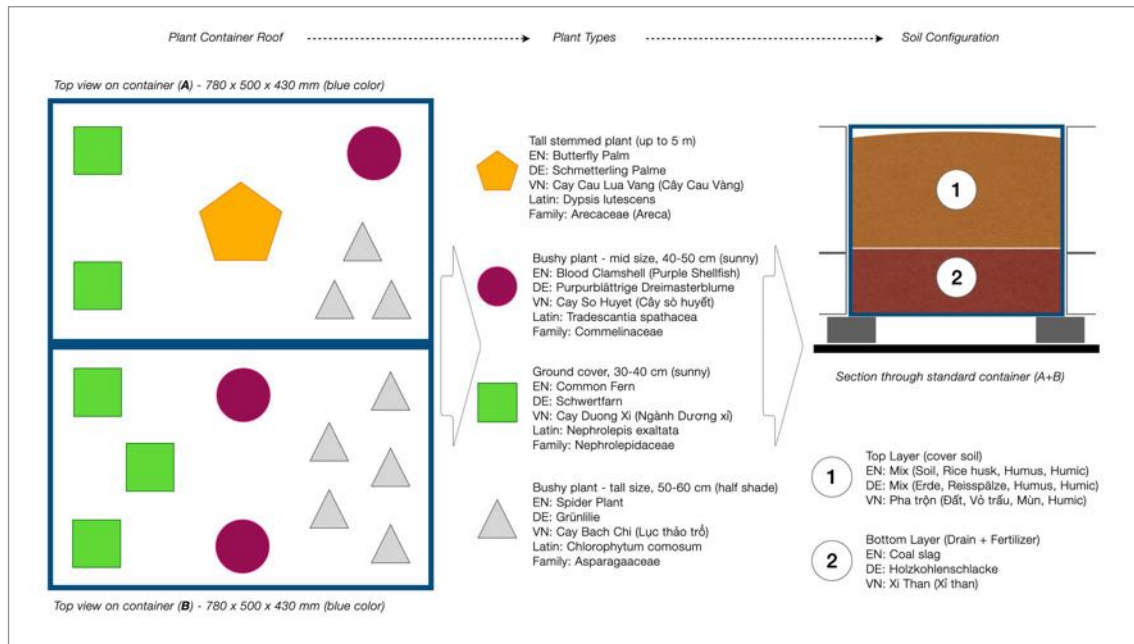


Figure 4.8: Configuration of the Plant Containers A + B

facade and intensive roof greening were coordinated and implemented in July 2024. Standard commercially available plastic containers with edge lengths of 780 x 500 x 430 mm and two distinct plant combinations (A and B) were employed to allow for a flexible alternation of the roof greening arrangement. The greening system was designed to be reversible, in the event that the property owner decides on dismantling after the research project's completion. The containers of Group A consist of four native evergreen plant species:

- Butterfly palm, *Dypsis lutescens* (canopy layer), heights of 2,0 - 2,5 m,
- Common fern, *Nephrolepis exaltata* (bush layer), heights of 0,5 m,
- Blood clamshell, *Tradescantia spathacea* (shrub layer), heights of 0,2 m,
- Spider plant, *Chlorophytum comosum* (shrub layer), heights of 0,15 m.

Containers of Group B contained the same plant species as Group A, with the exception of *Dypsis lutescens* (Figure 4.8). The containers were arranged in an alternating A, B, A, B, etc. sequence to provide sufficient space for plant growth. Sets of six and eight plant containers, respectively, were secured with tension straps (width = 5 cm) to withstand wind loads. All containers were elevated by 5 cm using bricks to avoid direct contact with the underlying surface. Each container base was equipped with eight drainage holes (d = 18 mm) and lightly covered with a fleece to ensure adequate water runoff and prevent substrate loss. All containers were filled with a homogenous mixture consisting of topsoil, rice husk compost, and humic substances (organic matter) as a 200 mm substrate layer (Layer 1), underlain by a 100 mm coal

slag drainage layer (Layer 2). The planting process was completed within two working days. The uppermost substrate layer was intentionally mounded to create a convex surface with a central elevation of at least 5-10 cm. This configuration aims to enhance solar irradiance exposure for the lower-lying plants. Simultaneously, the anticipated settling of the substrate over time will necessitate subsequent infilling, allowing for a more predictable maintenance schedule for substrate replenishment.

The facade greening was concentrated on the parapet wall of the south-facing and the exposed west-facing sides, which experience the highest solar radiation incidence during the day. Both sides were equipped with 27 smaller containers (C), with edge dimensions of 420 x 300 x 240 mm, arranged in three individual installations positioned on a cantilevered and white-painted metal structure mounted above the balustrade. Each container (C) was planted with two cascading *Vernonia elliptica* (Asterales: Vernonia (Cuc Tan An Do)) specimens, forming a natural curtain at a spacing of $a = 800$ mm in front of the facade. According to the existing structural design specifications, the maximum required load on balconies, roofs, and loggias is a maximum of 250 kg per square meter. The weights of containers A, B, and C are as follows:

plant container A containing butterfly palm, 90 kg

plant container B containing without butterfly palm, 85 kg

plant container C containing Cuc Tan An Do, 15 kg

For the implemented greening System eighty blue plastic container were placed and labeled as A_{con} and B_{con} . In addition to that 27 transparent plastic containers labeled C_{con} were used (Appendix C). Vertical forces on the roof are distributed as area loads while vertical forces through the parapet are calculated as line loads:

$$A_{con} \quad 40_{pcs} * 90 \text{ kg} = 3.600 \text{ kg} = 3,60 \text{ metrische Tonnen (t)}$$

$$B_{con} \quad 40_{pcs} * 85 \text{ kg} = 3.400 \text{ kg} = 3,40 \text{ metrische Tonnen (t)}$$

$$C_{con} \quad 27_{pcs} * 15 \text{ kg} = 405 \text{ kg} = 0,405 \text{ metrische Tonnen (t)}$$

Rainfall and irrigation can be accounted for by a 3% weight increase for containers A_{con} and B_{con} , and 8% for container C_{con} .

$$A_{con} \quad (x = (40 * 90kg) * 3\%) = \mathbf{3.708 \text{ kg} = (3,71 \text{ t})}$$

$$B_{con} \quad (x = (40 * 85kg) * 3\%) = \mathbf{3.502 \text{ kg} = (3,50 \text{ t})}$$

$$C_{con} \quad (x = (27 * 15kg) * 8\%) = \mathbf{437 \text{ kg} = (0,437 \text{ t})}$$

Area loads (kg/m²) accounted for container A and B including rainfall and irrigation:

$$\begin{aligned}
 A_i & \quad (x = 80 * (0,78m * 0,50m)) = \mathbf{31,2 \text{ m}^2} \\
 W_i & \quad (x = 3.708kg + 3.502kg) = \mathbf{7.210 \text{ kg} = (7,21 \text{ t})} \\
 \Sigma_a & \quad (x = \frac{7.210kg}{31,2m^2}) = \mathbf{231,09 \text{ kg/m}^2}
 \end{aligned}$$

Line loads (kg/lm) for plant container C including rainfall and irrigation:

$$\begin{aligned}
 A_i & \quad (x = 27 * (0,42m * 0,30m)) = \mathbf{3,4 \text{ m}^2} \\
 L_m & \quad (x = 4,840lm + 2,60lm + 3,60lm) = \mathbf{11,04 \text{ lm}} \\
 \Sigma_l & \quad (x = \frac{437kg}{11,04lm}) = \mathbf{39,58 \text{ kg/lm}}
 \end{aligned}$$

Occupation by greening (without shading):

$$\Sigma = 31,2m^2 + 3,4m^2 = \mathbf{34.6 \text{ m}^2}$$

In addition to the mentioned tension straps used for weight bundling and securing multiple containers, a supplementary structure based on standard commercially available bamboo poles was installed at a height of 400 - 500 mm above ground level and firmly connected to the containers. This measure was implemented to ensure safety and stability against local wind loads. The functionality of this reinforcement was demonstrated on September 7, 2024, when the historic Typhoon Yagi severely impacted Hanoi. The roof greening system withstood the wind loads, and the damage remained at a minimal level.

4.4.2 Miyawaki Method as Greening System

The Japanese botanist Akira Miyawaki (1928-2021) developed a methodology in the 1980s and 1990s of the preceding century to denaturalise forest areas and temporarily enhance urban brownfields, applying his "native forest by native trees" method (Miyawaki, 1998 & 1999; Kavana, 2023). Projects of this nature, also referred to as "Biofencing" (Kumar et al., 2023) in the context of greenbelts placed as buffers in transition to urban infrastructure, have been implemented on brownfields in Japan, South America, Malaysia, and Europe (Kavana, 2023). The core principle involves utilising a high diversity of native tree species per square meter to establish a natural environment conducive to plant growth. Following soil enrichment measures, specifically the incorporation of organic manures and soil loosening, 3-5 seedlings up

to a size of 1.2 m are planted as bare-root stock per square meter and subsequently covered with straw to regulate soil moisture retention. The saplings are managed for the initial two to three years against weeds to facilitate autonomous development thereafter. Ensuring forest autonomy by irrigating regularly, depending on climate and season, until the forest becomes self-sustaining without any need for pesticides or further intervention. The advantages of random seed distribution to mimic natural forest complexity and promote vigorous growth in this method promotes dense growth akin to natural forests, fosters the soil ecosystem, and creates refuge and breeding sites for birds and small animals. While the rapidly growing forest positively influences human health and furthermore contributes to the mitigation of air pollution in densely populated megacities of the Global South (Singh et al., 2019).

Therefore the roof greening on TestBed 1 and 2, this methodology was adopted and adapted in several respects to suit the specific conditions of the buildings first time in Vietnam. To obtain relevant microclimatic data, the high species diversity was reduced to establish comparable baseline assumptions. Consequently, five native plant species were selected and implemented in a grid pattern as detailed in Chapter 4.4.1. In addition to butterflies, local bird species were observed approaching the roof forests on TestBed 1 and 2. After eight months, a nesting site by a pair of birds in the branches of a palm tree in TestBed 2 provides empirical evidence supporting our hypothesis regarding the enhancement of local fauna. In summary a total of 734 individual plants were placed in the roof greening system.

4.4.3 Irrigation System

Irrigation was automated through a system that harvesting rainwater, grey and black water coupled with a Wilo pump and Abionik water filter unit, enabling continuous operation under local conditions (Figure 4.9) to measure the water flow via a water meter and corresponding valves (1, 2, 3). The pipes consist of standard commercially available PVC pipes ($d = 24$ mm) of a length over 50 m and flexible hoses ($d = 10$ mm) in length of 20 cm at the end of each PVC pipe. Water is delivered to the plants of plant container A and B via combination nozzles designed for both drip irrigation and fogging. Especially the Butterfly palm requires nebular cooling in the area of the shaft to avoid overheating. Hanging plants in the plant container C are exclusively supplied through drip irrigation nozzles at the end of a flexible rubber hose. Automatic irrigation was scheduled to operate at 8:00 AM and 8:00 PM daily, with a water volume of 125 liters per three-minute cycle. This cycle is adjusted seasonally.

The irrigation system implemented at TestBed 02 represents a significant advancement over the configuration used at TestBed 01. At this second installation site, upgraded outlet nozzles were deployed that allow for both targeted drip irrigation and fine mist

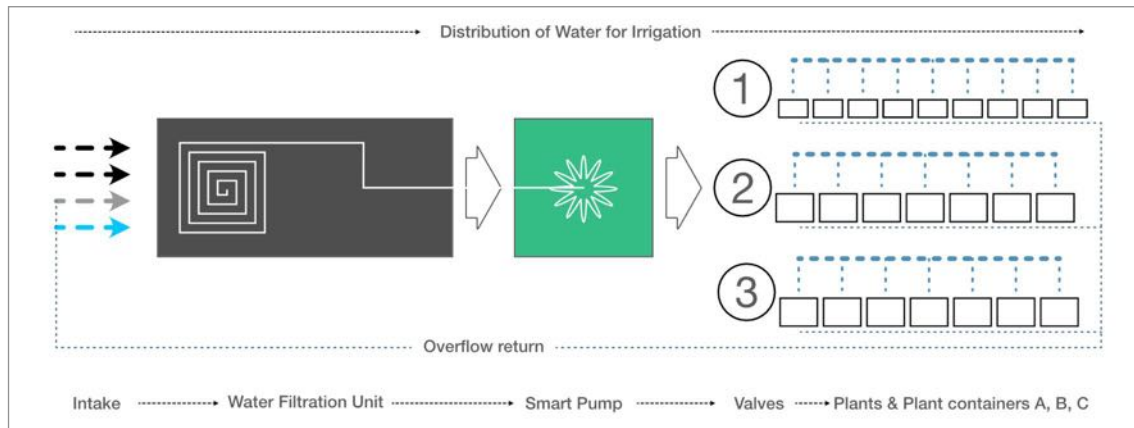


Figure 4.9: Irrigation System applied at TestBed 2

spraying Provided that sufficient water pressure is maintained, each nozzle can be manually and individually adjusted to the specific requirements of its associated planting container using a threaded flow control mechanism. The only notable limitation of this system lies in its operational reliability, which necessitates a higher degree of on site maintenance due its prototype configuration. In response to this, the irrigation infrastructure was comprehensively overhauled: the tank-based supply line was reconnected to the treated water (filtrate) supply line, and the system was reconfigured to reflect the current operating conditions after approximately ten months of use. The resulting increase in water pressure has improved the precision with which each nozzle can be calibrated. These iterative refinements contribute to valuable insights into system optimization under real-world conditions. Furthermore, TestBed 02 serves as a “proof of concept” for the mobile planting system developed in accordance with the Miyawaki afforestation method.

4.4.4 Maintenance Measures and Protective Structures

As a root supplement, the Japanese fertiliser HB-101 was applied at a dilution of 1:10 (v/v) to promote root development in *Dyopsis lutescens*. This measure was necessary given the severe root pruning undertaken prior to delivery, which increased vulnerability to wind-induced uprooting. A temporary wind-bracing system constructed from bamboo poles (20-30 mm diameter) provided additional support during establishment for palms with flexible, arching fronds.

During installation of the greening structures and anchorage elements, three types of fasteners were used: metal wire (0,5 mm, no coating), nylon cable ties (black and white), and flax twine (most natural). Under local climatic exposure, the metal wire exhibited early surface corrosion; black cable ties degraded rapidly, whereas white ties showed slightly longer service life. Flax twine performed best operationally: it tightens under rain and high humidity and tolerated wind loading effectively. Annual replace-

Table 4.5: Plants and Replacement

Type	Quantity A+B	Quantity C	Lost	Replacement
Butterfly palm, <i>Dypsis lutescens</i>	40	0	0	0
Common fern, <i>Nephrolepis exaltata</i>	200	0	2	0
Blood clamshell, <i>Tradescantia spathacea</i>	120	0	10	8
Spider plant, <i>Chlorophytum comosum</i>	320	0	37	37
Hanging plant, <i>Asterales vernonia</i>	0	50	0	0
SUM	680	50	49	45
Total	730			

ment of flax twine is recommended, while some cable ties required replacement after only weeks to months. Corrosion of the metal wire did not immediately compromise load-bearing capacity but accelerated under elevated air-pollutant levels typical for Hanoi; material specification should therefore be clarified (e.g., uncoated vs galvanised).

During the acclimatisation phase of the two green roofs on TestBed 1 and 2, the disposal of dry leaves and branches from the palms was significantly more frequent. This rate decreased considerably during the establishment phase, albeit with some dependence on the specific location. In addition to TestBed 1, a significantly delayed establishment and acclimatisation phase was observed in TestBed 2, attributable to the exposed location of the roof. This exposure resulted in intensified wind currents and stagnation zones, leading to the formation of heat pockets that induced stress in the plants. The displacement of these heat pockets across the roof further contributed to delays in establishment (Schaefer et al., 2025). These stress factors prolonged the recovery period, necessitating more intensive initial maintenance until the plants had sufficiently recovered to allow for a normalisation of care requirements. Furthermore and in contrast to TestBed 1, TestBed 2 experienced a snail infestation in containers A and B during the acclimatisation phase. The garden snail caused losses in the topsoil and shrub layer affecting plants of the genera *Tradescantia spathacea* and *Chlorophytum comosum*. The juvenile plants were irretrievably lost over a period of the first four to six weeks in five affected plant containers. During a subsequent site visit to TestBed 2 in early October 2024, the hollow snail shell was discovered. Following an inspection of the plant stock in late 2024 and early 2025, offshoots of the plants in

TestBed 1 were collected and replanted in TestBed 2 (Table 4.5). Species dynamics diverged between sites. On TestBed 1, *Chlorophytum comosum* declined while *Tradescantia spathacea* thrived under the prevailing light regime. Conversely, on TestBed 2, the reduced vertical growth of *Dyopsis lutescens* increased shading within the shrub and ground-cover layers, favoring *Chlorophytum comosum*, which partially to fully displaced the neighbouring *Tradescantia spathacea*, consistent with its higher shade tolerance. These observations during installation inform material selection (fastener specification), replacement intervals, and early-phase maintenance scheduling for rooftop greening in subtropical urban climates, and they underscore the role of micro-site wind and heat patterns in establishment success.

4.4.5 Sensor Network and Visual Monitoring

For comprehensive environmental monitoring at TestBed 02, a network of meteorological sensors was deployed at six rooftop locations, as illustrated in Figure 4.10. These were organised into four primary measurement axes, each for specific observational purposes:

A. Vertical Axis 1:

One wireless DAVIS Vantage Pro2²² weather station, solar-powered and mounted on a galvanised steel pole (5.0 m height, 48 mm diameter), fixed with four hexagonal bolts to the southern rooftop façade. Beneath the station a DAVIS EnviroMonitor Gateway²³ collects sensor data and transmits it to the DAVIS Cloud.

B. Vertical Axis 2:

Two DAVIS Nodes equipped with sensors for surface temperature, leaf wetness, soil moisture, air temperature, and relative humidity.

C. Horizontal Control Axis – South (800 mm distance):

Three Nodes gather data through sensors for air temperature and relative humidity; additional sensors monitor wall surface temperature.

D. Horizontal Axis – South (800 mm distance):

Air temperature, relative humidity, and façade surface temperature sensors.

E. Horizontal Control Axis – West (250 mm distance):

three Nodes gather data through sensors for air temperature and relative humidity. additional sensors monitor wall surface temperature.

F. Horizontal Axis – West (250 mm distance):

²² <https://www.davisinstruments.com/collections/vantage-pro2/products/wireless-vantage-pro2-plus-iss-with-24-hr-fan-aspirated-rad-shield> (06.05.2024)

²³ <https://www.davisinstruments.com/products/enviromonitor-gateway> (06.05 2024)

Air temperature, relative humidity, and façade surface temperature sensors.

Horizontal sensor axes were mounted on custom-fabricated steel brackets painted white to reduce heat absorption and thereby minimise potential interference with data readings. Each bracket was fixed to the facade using four hexagonal bolts and local available dowels, while temperature sensors were attached with galvanised screws or just laid into prepared holes. Cabling was arranged with cable ties and fastening wire to ensure stability and minimise disturbance. Sensor nodes were placed on steel poles (1.5 - 2.0 m in height), anchored either to the parapet or within planting containers to withstand wind loads using rubber straps. Each node supports up to four sensor inputs, allowing flexible integration of monitoring devices. This modular configuration facilitated the targeted placement of sensors on south- and west-facing facades, prioritised due to their higher solar exposure. In addition, a vertical sensor rod embedded within the rooftop vegetation enabled comparative analysis of thermal dynamics between the green roof and exposed surfaces.

To complement the environmental sensor data with visual observation, a remote-controlled IMOU Cruiser SE 2MP IoT²⁴ surveillance camera was installed beneath the meteorological weather station with a 64GB MicroSD card. This component provides real-time image-based monitoring of rooftop vegetation and infrastructure.

Key specifications and integration aspects:

- Camera Type: IMOU Cruiser SE 2MP (Model: IPC-S6DP-3M0WE)
- Resolution: 2.0 megapixels (1920 × 1080), full HD streaming
- Lens & Field of View: 3.6mm fixed lens with 93° diagonal viewing angle
- Rotation Functionality: 355° horizontal pan / 90° vertical tilt
- Night Vision: IR and spotlight-based enhanced night mode, up to 30m range
- Connectivity: Wi-Fi (2.4 GHz) with RJ45 port for wired LAN
- Storage Options: MicroSD card and IMOU Cloud
- Weather Resistance: IP66-certified waterproof and dust proof housing
- Power Supply: 12V DC input, surge protection integrated
- Software Interface: IMOU Life App (iOS/Android) for remote live viewing, PTZ control, screenshots, and event recording
- Mounting: Fixed below the DAVIS pole mast using a stainless-steel mounting bracket with vibration dampers

²⁴ <https://www.imou.com/en/product/detail/cruiser-se-plus> (28.07.2024)

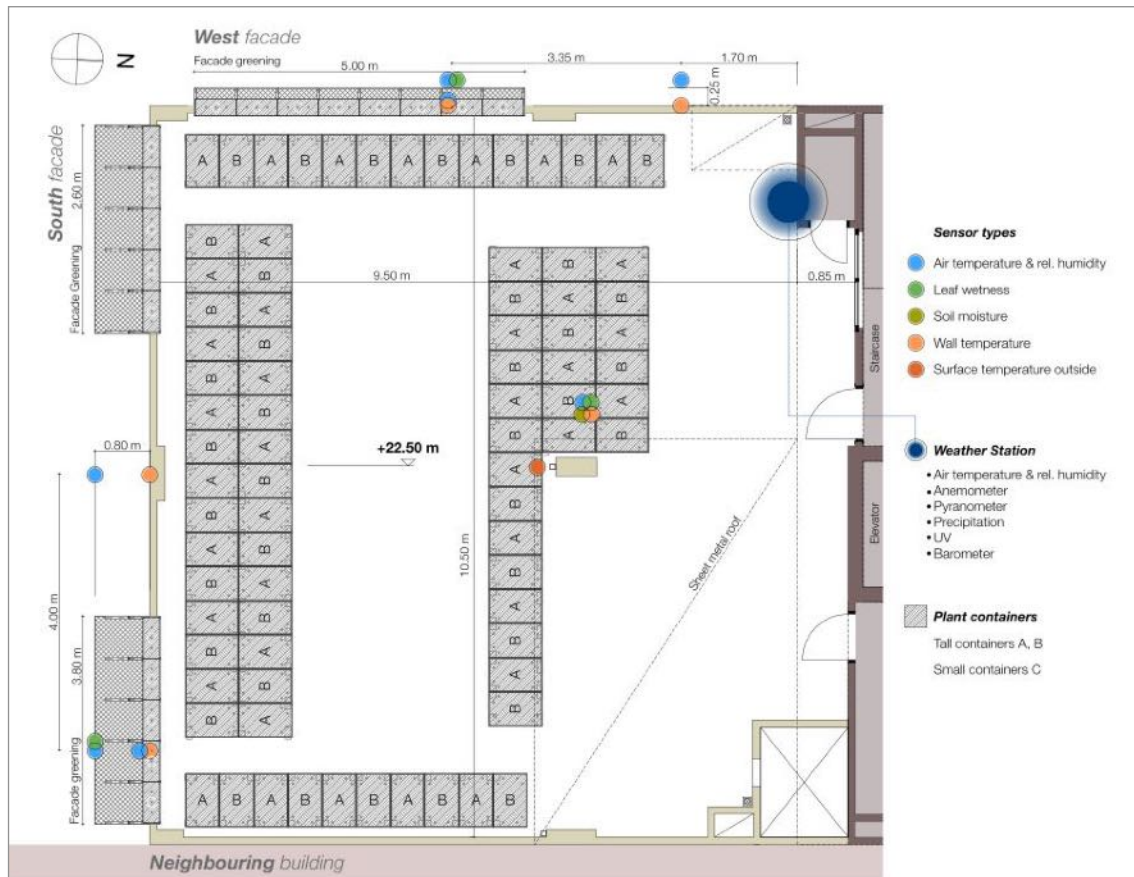


Figure 4.10: Sensor Placement on TB2

Planning and conceptual development of TestBed 02 were conducted in Germany, following the precedent set by TestBed 01. Initial coordination with the building owner was facilitated through private channels. Preliminary sketches were used to communicate the project concept and secure consent. This enabled an integrated planning approach, incorporating all methodological insights and objectives derived from previous project phases. The sensor network could be set into place within five working days.

4.4.6 Economics of the Greening System

As part of supervising a Master's thesis on the economic feasibility and maintenance of building greening through roof and facade systems at TestBed 2, two on-site inspections were conducted. Shortly after completion of the greening works, water meter readings and irrigation valve data were recorded twice daily. At the same time, all relevant cost components for materials, plants, and installation were cross-checked.

The thesis was structured around a life cycle perspective, with emphasis on both Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). The LCC framework included

four principal categories:

1. *Initial Costs* – comprising planning, materials, plants, logistics, and installation of the irrigation system.
2. *Operating Costs* – covering water consumption, routine plant care, and cleaning.
3. *Maintenance Costs* – including upkeep of the irrigation system and roof structure.
4. *Disposal Costs* – considering the eventual dismantling and removal of the greening system.

Each cost category was projected over a 50-year period to ensure comparability with established building life cycle frameworks. The approach thus combined quantitative monitoring data (e.g., water consumption) with cost modeling for recurring and long-term impacts. To extend the findings beyond the scale of TestBed 2, the results were extrapolated to the Tonkin 2 residential tower, allowing the cost framework to be applied to a high-rise case scenario. This scaling process provided insights into the economic implications of facade and roof greening in dense urban contexts, highlighting both the potential and the challenges of transferring experimental results into large-scale residential construction.

4.5 Field Study Water Infrastructure

4.5.1 On-Site Conditions

The basement accommodates the WA-MBR-TB225 water filtration system, installed by the project partner WILO Abionik, alongside its secondary function as a motorcycle parking area. The L-shaped floor plan (Appendix B.2) allowed placement of the filtration system along the access ramp, covering a footprint of approximately 10.5 m². The ramp, with a slope of 35%, provides the only access from the rear alley and also serves as the direct fire exit. Natural ventilation is ensured year-round through the open ramp and a metal-framed entrance gate at the property boundary, securing adequate air circulation within the space. The system layout was designed to compactly accommodate all critical components while ensuring compliance with requirements for ventilation, maintenance access, and escape-route clearance. The location offers short, direct connections to the building's pipe infrastructure and meets essential spatial and safety standards. Four separate greywater and blackwater lines (DN 90/110) connect to the filtration system. Adjacent to the filtration unit is the control panel for the building's fire suppression system, also operating on a 400 V power

supply. The main electricity meter is located on the second-floor stairwell landing, serving as the principal access point for the filtration unit's power demand. Additional basement features include a lockable storage room and access to the service-water cistern (freshwater intake). Two booster pumps for fire protection are mounted on a raised concrete platform, while the delivery pump conveys treated water to two rooftop storage tanks (2 m³ each) at a height of +25.00 m. The basement walls are plastered and painted white; the floor is finished with 600 × 600 mm ceramic tiles. A drainage gutter - made of cast iron - is positioned at the ramp transition, functioning both as a rainwater collector and as an overflow outlet for the filtration system. The ramp surface consists of grooved concrete to improve traction.

The basement clear ceiling height is 2.35 m, with reduced clearance of 2.05 m beneath beams. The lowest passage height of 1.94 m at the ramp-beam transition influenced the logistical planning and dictated the maximum installation height of system components. The lowest section of the water-bearing pipe system is positioned at 1.90 m above finished floor level. These construction parameters were decisive for the spatial calibration of the unit during the preliminary design phase.

According to as-built drawings, the ceramic floor has a specified load-bearing capacity of 750 kg/m². The building contains 24 rental units with an estimated daily occupancy of up to 50 persons. Peak sanitary demand occurs between 08:00 - 10:00 and 19:00 - 21:00, when elevated water consumption is expected. In addition, rooftop laundry facilities with multiple washing machines operate throughout the day, each consuming an average of 40–60 L per washing cycle. Current per capita water consumption in Vietnam averages between 120 and 150 liters per day, depending on regional and urban conditions (Ötaki et al., 2013; DAWACO, 2023). Based on these benchmarks and internal estimations, the total daily consumption for the building is approximated at 6,500 liters (6.5 m³). Accordingly, the filtration system was dimensioned to meet this demand, with a standard processing capacity of 5 - 7 m³ per day, providing a sufficient margin under peak usage conditions.

4.5.2 Waste Water Treatment Plant (WWTP)

In collaboration with the project partner and technical manufacturer WILO and its subsidiary Abionik GmbH, the manufacture's smallest unit membrane bioreactor (MBR) BMA-1075²⁵ - later renamed and commissioned as WA-MBR-TB225 waste water treatment plant (WWTP) was developed based on the technical pre-planning of the research building. The unit is capable of process the wastewater generated by up to 50 people. Abionik, acting on behalf of its parent company WILO, specialises in the

²⁵ <https://abionik.com/en/products/wastewater-treatment/mbr-package-plants> (06.09.2024)

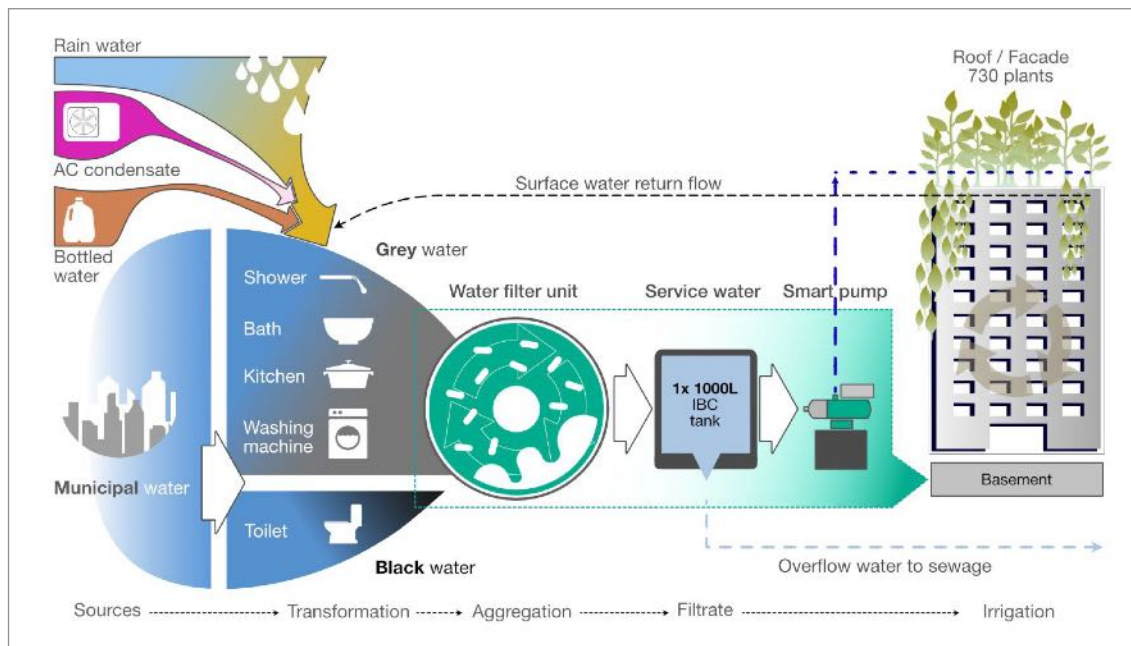


Figure 4.11: Water Cycle within TB2

production of membrane-based water treatment systems for inland and maritime applications. These systems are designed to treat wastewater for user groups ranging from 50 to 5,000 individuals. Within the scope of this research project, the WA-MBR-TB225 WWTP was implemented for the first time in Vietnam in a fixed building context. Initial challenges arose due to the fundamental differences between marine and building technology requirements. These discrepancies were addressed and resolved during the project planning phase.

To guide the conceptual development, a visual systems model (Figure 4.11) was created to explain the water cycle or water loop to the local participants and owner family to explain resource saving technology. This diagram defined the overall framework of the water cycle, as well as the associated functions and performance expectations of the filtration system. Based on this framework, the system design and implementation were coordinated closely with the building owner and the responsible engineering consultants and with support of local labors.

The technical configuration of the WA-MBR-TB225 consists of seven core components that together enable a closed-loop water cycle and efficient irrigation of the rooftop and façade greenery:

- (a) Mix tank
- (b) Screening
- (c) Denitrification reactor
- (d) Nitrification reactor

- (e) Filtrate tank
- (f) Exhaust
- (g) Wilo Pump (Medana smart pump)

Each component is constructed from corrosion- and chemical-resistant materials, detailed as follows:

- | | |
|-----------------------------|----------------------------------|
| (a) Mix tank | High-density polyethylene (HDPE) |
| (b) Screening | Stainless steel |
| (c) Denitrification reactor | Polypropylene (PP) |
| (d) Nitrification reactor | Stainless steel |
| (e) Filtrate tank | High-density polyethylene (HDPE) |
| (f) Exhaust pipe | Polypropylene (PP) |
| (g) Wilo Pump | Die-cast aluminum |

The standardised process flow of membrane-based wastewater treatment, as defined in the piping and instrumentation diagram, is also visualised via the local system display in the building's basement. Due to the structural constraints at the installation site, several adaptations were necessary. These modifications included a reconfiguration of the module layout and the directional flow path (Figure 4.12), without altering the underlying process sequence. The adjustments were limited to the length and routing of interconnecting pipelines. Connection points on the top of tanks (a), (c), (d), and (e) are equipped with standard sockets for PVC piping (DN 90/110), securely linking the modules and guiding the flow toward the downstream activated carbon filter. Overflow ports on tanks (a), (b), and (e) prevent unintended spillage. The filtrate water later is guided to the smart pump from Wilo that supplies the irrigation system on the roof.

Figure 4.12 (c) sketches the power supply provided via a five-core heavy-duty cable (400 V, $5 \times 4.0 \text{ mm}^2$), extending 25 meters from the main distribution board located on the second floor to the basement socket. A 400V CEE industrial socket ensures the secure connection to the filter unit WA-MBR-TB225. While four-core cabling with combined neutral and protective conductors (N/PE) is standard in Vietnam, the German-supplied five-core cable (L1, L2, L3, N, PE) was compatible without requiring bridge connections. This is due to the national utility provider EVN (Energy Vietnam) already supplying five-core cables to buildings, where the connection between N and PE is made in the main panel. In addition to that, the WA-MBR-TB225 is therefore directly integrated into the building's electrical system. Power consumption is monitored via a separate digital meter, allowing precise tracking. For safety reasons,

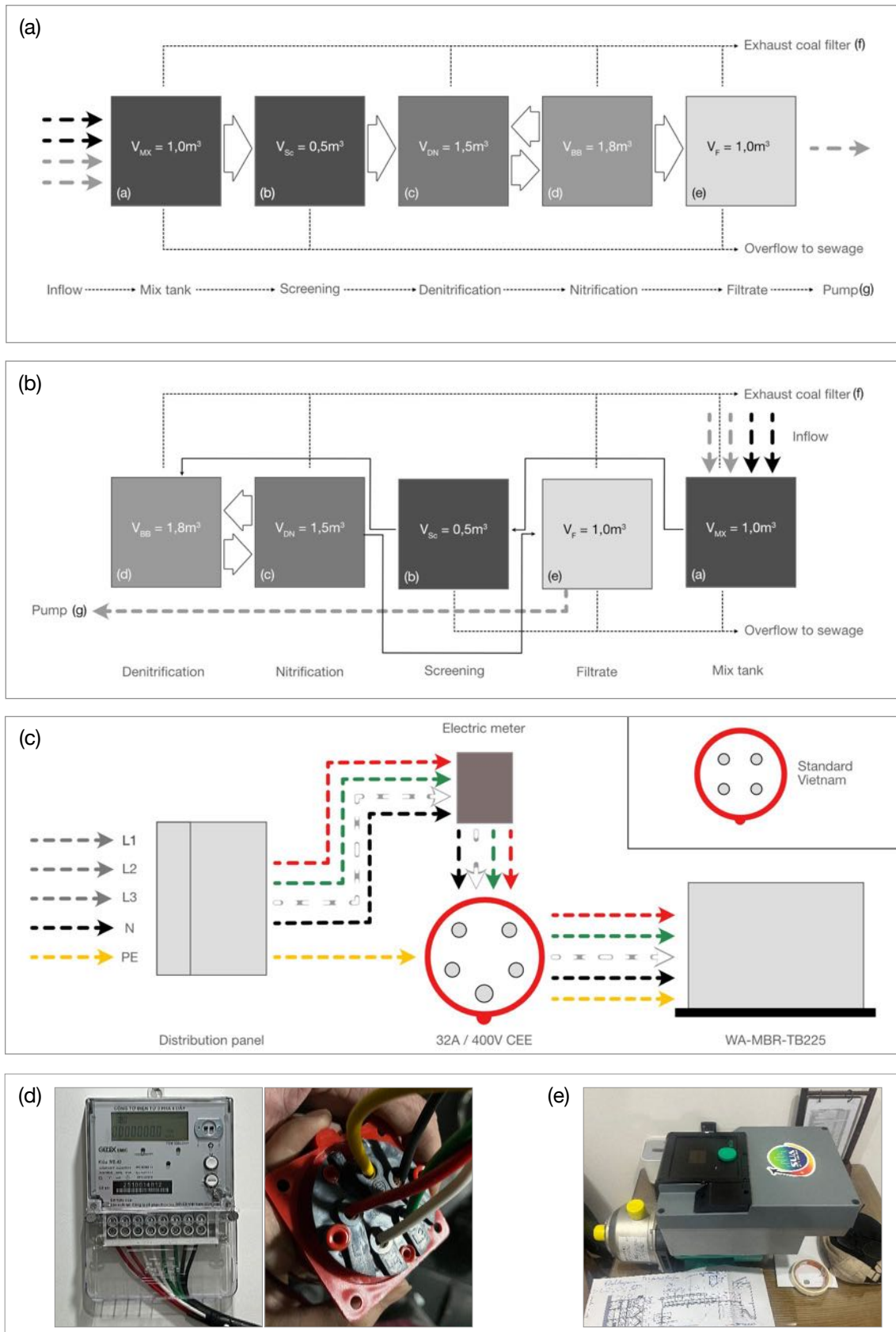


Figure 4.12: (a) Rul - Flow Diagram (simplified, Standard), (b) Rul Modification Arrangement on Site, (c) Electric Adjustment from EU to VN, (d) Digital Meter and five-core Socket Solution, (e) Smart Pump for Irrigation System before Implementation

the 32 A / 400 V CEE socket was mounted on a ceiling beam, above head height, to avoid potential hazards associated with flooding or water overflows. The activated carbon filter is positioned outside the building near the ramp access. In order to visually harmonise with the architectural setting, the associated piping was retroactively painted white.

Commissioning Process and Water Treatment:

The wastewater treatment plant (WWTP) WA-MBR-TB225 is designed for the treatment of grey water, laundry water, black water and kitchen wastewater from the apartments, as well as rainwater collected from the balcony and roof drainage downpipes. In accordance with DIN 4045, all influent is initially stored in a mixing and equalisation tank (mix tank) to balance flow and pollutant load. From there, it is transferred to the treatment system via a submersible transfer pump in compliance with DIN EN ISO 5199 a technical norm for centrifugal pumps. The treatment process consists of three principal stages, as defined in DIN EN 12255²⁶:

1. Mechanical separation (DIN EN 12255-3),
2. Biological treatment (DIN EN 12255-6), and
3. Membrane filtration (DIN EN 12255-16),

To initiate the three treatment stages, it is recommended that the system be seeded with aerobic activated sludge (Bùn thải) to establish bacterial cultures in both the denitrification and nitrification tanks. This promotes effective biological activity, enabling the wastewater to be treated and reused as non-potable service water for irrigation purposes. Implementing this measure proved challenging at the local site. Instead, sugar and effective microorganisms (EM) were introduced as alternative inoculants. Trials using both approaches revealed that bacteria—particularly those thriving on black water—were difficult to cultivate due to significant differences in wastewater composition compared with Western systems.

The filtration circuit operates autonomously, with electronic control and a predefined internal piping layout. Consumption values are displayed on the control panel, while energy use is recorded manually from the digital power meter on a weekly basis, though not always consistently.

Ball joints are installed on the four main wastewater pipes, allowing for positional adjustment and enabling the system to be disconnected from the filtration unit and later reconnected to its original configuration if required for maintenance or operational

²⁶ <https://www.baunormenlexikon.de/norm/din-en-12255-3/9aae0c07-0af0-4472-9a09-e3d3e33b56a7> (11.07.2025)

purposes.

Mechanical Separation:

In the first stage, the wastewater undergoes mechanical pre-treatment (screening), whereby coarse particles and solids are removed from the collected influent to prevent membrane clogging by large debris. All wastewater must initially pass, under gravity flow, through the fine screen fitted with a 1 mm perforated plate. Solids such as toilet paper, hair, and fibrous materials, which could cause undesirable obstructions in the process, are retained in the screening basket. The organic matter contained in the screenings, serving as a carbon source for the biological treatment stage, is washed out and subsequently degraded during the biological process. The wastewater enters the screenings tank, where its velocity is reduced. Specifically heavier particles sink to the bottom by gravity, while lighter materials float to the surface. The wastewater then rises upwards through a riser pipe and passes through the fine screen. A rotating brush in the fine screen cleans clogged pores and, due to its lamellar and spiral configuration, conveys the coarse materials downwards into the screenings tank. A hydrostatic level sensor is installed in the screenings tank, and the brush's rotation is level-controlled. To loosen stubborn blockages, the direction of the brush's rotation can be manually reversed. A pump-driven suction system is located at the base of this treatment stage, which reintroduces the residual materials into the wastewater line downstream of the ball valves.

Biological Treatment:

In the second stage, biological wastewater treatment is carried out using the activated sludge process. In two aerated filtration reactors, the wastewater is biologically purified by microorganisms (activated sludge) under the supply of bubble aeration. The suspended microorganisms utilise the constituents of the wastewater as a nutrient source for their metabolism. The biological treatment is implemented in two steps to achieve maximum degradation efficiency:

1. Anaerobic process – upstream denitrification:

In the denitrification reactor, anaerobic microorganisms reduce the wastewater constituents under anoxic conditions. To homogenise the activated sludge, air is introduced cyclically via membrane tube diffusers located at the bottom of the tank. A hydrostatic level sensor monitors the water level and controls the filtration process or the filtrate pump. System-defined set points for 'filtration volume' and 'filtration stop' are stored in the control unit.

2. Aerobic process – downstream nitrification:

This step takes place in the filtration reactor, where aerobic microorganisms

oxidise the wastewater constituents under oxygen supply. Oxygen is provided via membrane tube diffusers and the aeration blower. The sludge volume index must be measured regularly, and the dry solids content (TS) adjusted to a range of 8 - 12 g/l measured. Excess sludge is continuously returned to the wastewater line.

For regular TS the treatment unit provides a one liter container with scale. In the phase of commissioning the measures were taken every third day. The water has two rest for 20 minutes before receiving a reliable value. Based on the 'artificial or external' feeding bacterias are able to grow until the develop themselves on their own.

Membrane Filtration:

Membrane filtration is a physical separation process for solid-liquid separation. The driving force of the separation mechanism is a pressure differential between both sides of the membrane, referred to as the transmembrane pressure (TMP). The resulting flow through the membrane is known as the flux. In the designated Abionik Cube process, synthetic, polymeric, static flat membranes with a separation limit of 35 nm from the field of ultrafiltration (UF) are in use. Consequently, all substances with a particle diameter larger than the membrane pores, such as the smallest microorganisms (bacteria), are retained. Water and dissolved constituents pass through the membrane and form the filtrate.

During continuous membrane operation, a surface layer forms on the membrane. The formation and compaction of this layer - comprising mainly biomass and extracellular polymeric substances (EPS), as well as colloids embedded in the EPS - is referred to as fouling. To reduce fouling, an overflow across the membrane is induced, known as cross-flow filtration. The shear forces generated in this process cause parts of the surface layer to detach and return to the activated sludge. As the final treatment step, ultrafiltration membranes are installed in the filtration reactor to physically separate the treated wastewater from the activated sludge.

Treated Water Analysis:

The filtrate is stored in a 1 m³ Intermediate Bulk Containers (IBC) with overflow. When the maximum fill level is reached, the filtration process is limited to prevent overflow. In addition to avoid any inconvenience for the building owner and operator the filtration IBC tank was equipped with a DN 40 PVC pipe as overflow. The filtrate than is able to be used for irrigating the garden areas located on the roof of the residential complex. Further investigation was conducted into water quality of the treated water in comparison to the municipal water in collaboration with the Institute of Chemistry of the Vietnam Academy of Science and Technology in Hanoi. The intention for this clarification was the use of treated water for washing machine, that generate the most

water consumption overall per day. Using filtrate water for washing machine would be a major upgrade towards sustainable hotel operating and handling of water resource.

4.5.3 Installation Process and Monitoring

The delivery of the Intermediate Bulk Containers (IBCs) and associated modules for the WA-MBR-TB225 system - delivered from Germany - was organised through local logistics providers and with support from the project partner Wilo. In accordance with Hanoi's traffic regulations, which restrict truck access during daytime hours, delivery was scheduled for the evening. The system components arrived on site at 22:00 via a crane-equipped truck. Two key modules - the nitrification treatment unit and the denitrification reactor - were transported in wooden crates. Customs documentation recorded the nitrification module at 1,800 kg (2,770 × 1,860 × 1,900 mm) and the denitrification unit at 650 kg (2,320 × 1,450 × 1,900 mm). International shipping and customs clearance were coordinated by the German technology partner, while local on-site logistics were supervised by Wilo Hanoi.

Unpacking and positioning required staged procedures adapted to the spatial constraints of the alleyway and basement. The protective OSB (Oriented Strand Board) coverings and bolts were removed on site, and the modules were transferred on locally rented pallet jacks (3,000 kg load capacity). Up to six workers transported the components through a 2.20 m wide alley to the building entrance. An initial attempt to lower the stainless-steel nitrification unit into the basement via pulley system was aborted for safety reasons, whereas the lighter denitrification tank was successfully placed manually. The following day, the filtration unit was moved into the basement by ten workers using a carpet runner to control movement on the steep access ramp and to protect the ceramic flooring. At the ramp-floor transition, the module was lifted onto pallet jacks and manoeuvred into its predefined installation position, determined in advance to ensure clearance for building services within a total available floor area of 10.5 m². Once positioned, the denitrification unit and two IBC tanks (mix and filtrate) were integrated according to the adjusted layout.

Subsequent installation involved piping and electrical connections. A Wilo Medana smart pump was installed to supply treated water to the preconfigured rooftop irrigation infrastructure. For vertical transport, a DN 30 polypropylene random copolymer (PPR) riser was mounted in the escape stairwell, designed for accessibility and maintenance. At roof level, this line connected to a DN 20 PVC pipe with a valve fitting, distributing water via flexible tubing (6–8 mm) to drip irrigation and misting nozzles. Pipe fittings and connectors were procured from local sanitary suppliers. Routing was implemented manually by the project team in coordination with the German partner, taking into account structural limitations of the building.

Following connection to the 32 A / 400 V CEE industrial socket, the system underwent a multi-day functional test. This phase included leak detection, pump performance verification, and gasket integrity checks. Integration into the building's wastewater infrastructure required the preparation of four DN 90/110 ball valves. An initial late-night connection attempt was discontinued for safety reasons; final integration of greywater and blackwater discharge lines into the mix tank was completed the following day during off-peak occupancy. During commissioning, irregularities in pump performance were identified through the system control panel and rooftop pressure measurements. These were resolved iteratively.

For example, the filtrate piping was reconfigured: the DN 30 PPR originally installed was replaced by DN 60 PPR up to the Wilo circulation pump (PH-401E), then reduced again to DN 30 PPR. Synchronised operation of the circulation pump with the Wilo Medana pump achieved the required irrigation pressure. Final calibration was carried out via the Medana pump interface.

To minimise vibration and noise emissions, the system was placed on 8 mm rubber mats (1 m wide, 16.6 kg/m² surface mass), which also added a protecting layer to the tiled flooring. Two axial fans (650 mm diameter) were installed on the rear basement wall to secure air circulation and mitigate odours from fermentation gases; these can be manually operated and oriented as required.

Installation was completed in twelve calendar days, including weekend work, so the overall logistics - from preparation to completion - extended over two months (mid-December 2024 to mid-February 2025). Technical planning and custom fabrication required an additional three months, and the entire process from initial consultation to commissioning spanned approximately twelve months.

Training sessions accompanied installation and trial operation, enabling local partners and Wilo Hanoi staff to independently monitor and service the system. For remote monitoring and technical support, a STARVIS™ CMOS 2 MP WDR network camera was installed, connected via 4G SIM card to a smart video recorder and WiFi router, allowing access to the WA-MBR-TB225 control panel through the CMSS application.

Excess water from irrigation, planter drainage, and rainfall is redirected into the building's rain gutter system, thereby closing the water cycle at the site scale.

5 Results and Discussion

The preceding chapter outlined the methodological approaches in detail. This chapter presents the key findings derived from these methods and discusses their implications for the development of urban districts.

5.1 Thermographic Imaging - Results and Reflections

Results

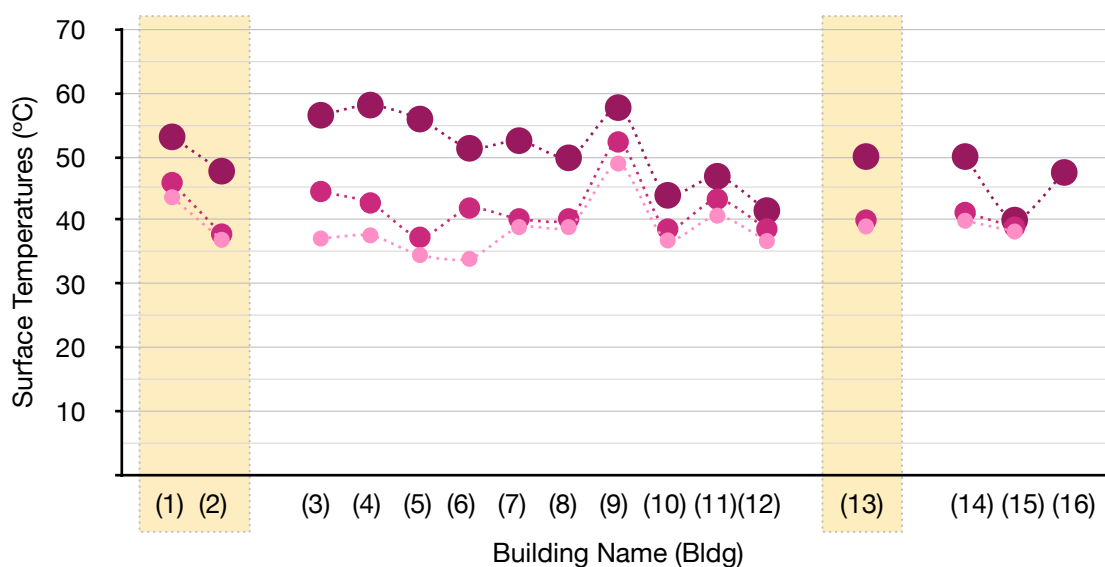
Surface temperatures at survey buildings and comparable buildings in Hanoi:

The following list presents surface temperature data from the west-facing facades of residential high-rise buildings in Hanoi, serving as a comparative reference for the facades of Tonkin 1 and Tonkin 2. Owing to its position in the sunset direction, Tonkin 2 was partly overshadowed by Tonkin 1. Measurements were carried out on 7 August 2024 between 15:00 and 16:00, coinciding with the onset of afternoon traffic congestion. Within this time frame, the installed sensor system captured the period of peak heat intensity. Table 5.1 provides an overview of the measured surface temperatures, differentiated by facade orientation and building height. The buildings comparable to Tonkin 1 and Tonkin 2 range from 30 to 70 floors, while TestBed 2 is compared with its direct eastern neighbour of nine floors and another residential building with 4 floors facing West. Specifications of the facade in general are primarily composed of cement render applied to a brick masonry core, supplemented by glass and metal elements. From three to four thermal measurements on the high-rise facades, the minimum and maximum values were recorded in the list. Where additional measurements were available, these were consolidated into an average value for inclusion. Notable are facade surface temperatures consistently exceeding 51 °C, as well as average values of approximately 39 - 42 °C, which impact on the facades between 13:00 and 18:00. This indicates that thermal loads are transferred into the masonry of the building envelope. This effect could be verified more clearly at TestBed 2: wall-mounted sensors, together with external and internal thermal measurements on the west-facing wall, confirmed the storage and release of heat loads within the masonry. For the interior, this translates into an increased reliance on artificial ventilation systems, i.e. AC systems. In most cases, air conditioning is employed to maintain indoor air temperatures at approximately 27 °C. The data indicate that these air-conditioning systems operate continuously, in some instances throughout the night, a pattern previously confirmed in Hanoi by a survey conducted within the CAMaRSEC²⁷ project in collaboration with the author of this study.

²⁷ <https://bmbf-client.de/projekte/camarsec> (12.05.2023)

**Table 5.1: Surface Temperatures of West-Facing Facades,
Date 07.08.2024, 15:00-16:00**

Building Name (Bldg)		Minimum (Min)	Average (Avg)	Maximum (Max)
Tonkin 1 (T1)	(1)	43,6 °C	45,9 °C	53,1 °C
Tonkin 2 (T2)	(2)	36,9 °C	37,8 °C	47,7 °C
Diplomatic Area N0/T1	(3)	37,1 °C	44,5 °C	58,1 °C
Diplomatic Area N0/T7	(4)	37,6 °C	42,7 °C	56,5 °C
Diplomatic Area N02	(5)	34,5 °C	37,3 °C	55,9 °C
Diplomatic Area N03	(6)	33,9 °C	41,9 °C	51,3 °C
Diplomatic Area N04	(7)	38,9 °C	40,2 °C	52,5 °C
Kosmo Tay Ho	(8)	38,9 °C	40,2 °C	49,8 °C
Starlake Samsung	(9)	48,9 °C	52,3 °C	57,7 °C
Nghia Do CT3	(10)	36,8 °C	38,6 °C	43,9 °C
Landmark 72	(11)	40,7 °C	43,3 °C	46,9 °C
Smart City Imperia	(12)	36,7 °C	38,6 °C	41,4 °C
		38,71 °C	41,94 °C	51,23 °C
TestBed 2 (TB2)	(13)	39 °C	40 °C	50 °C
TB2 Neighbour East	(14)	39,9 °C	41,2 °C	50 °C
TB2 Neighbour East (20:30)	(15)	38,2 °C	38,9 °C	40 °C
Ciputra D5	(16)	—	—	47,5 °C



Comparative surfaces:

Comparative surface measurements during this period provide insights into the general processes of heat absorption and reflection, which contribute to plant heat stress (Schaefer et al., 2025) and to the formation of urban heat islands. The temperatures presented in Figure 5.2 illustrate the behaviour of construction materials commonly used in Hanoi. Alongside the traditional terracotta tile for rooftops, roofs and upper floors are often constructed as lightweight metal structures clad in corrugated sheet metal. This material is commercially available in red, blue, green, and dark grey, while white-coated sheets remain uncommon. By contrast, Korean and Japanese factories more frequently clad large production halls in white corrugated sheets. In Hanoi, particularly in industrial areas and technology parks, large halls are frequently clad in red, green, and especially blue sheet metal, exposing workers inside to extreme heat stress.

The widespread use of blue, green or red cladding remains largely unexplained. Anecdotal explanations point to cultural or symbolic associations, including Feng Shui principles or the perception of blue as a 'cool' colour. Such interpretations illustrate the interplay between spiritual-cultural knowledge and artistic colour theory, yet they diverge from the physical properties of solar heat absorption across different colours. Similar patterns were observed in the Vinhomes Smart City development, where the roof of a kindergarten was painted blue and playground surfaces (Appendix A.1) were covered with artificial turf placed directly alongside natural grass. Direct measurements confirmed the differentiation of heat extremes between such surfaces by 50%.

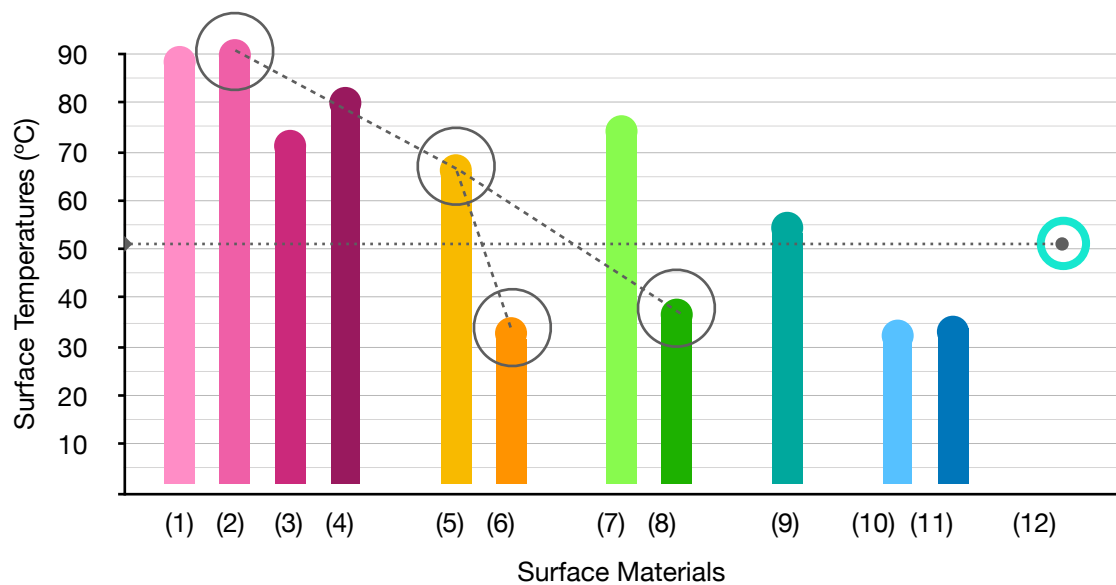
The dataset also includes a reference measurement obtained through thermal imaging of the upper side of the implemented palm trees, as well as two further reference measurements taken from the inside of TestBed 2. By contrast, no relevant thermal recordings could be obtained from the inside of the Tonkin Towers due to privacy restrictions. Overall, thermal images taken from the rooftop of TestBed 2 into the surrounding urban fabric at midday provide evidence of a general heat layer of approximately 51 °C. The readings of metallic and ceramic surfaces stand in marked contrast to the much lower temperatures recorded in shaded vegetated areas. The interior measurements, meanwhile, provide additional insights into construction quality and heat emission from the building envelope.

Thermal bridges:

Thermal bridging plays a significant role in the performance of high-rise buildings and other constructed objects in Hanoi. Ideally, the building envelope should be designed to prevent external heat while retaining internal cooling. The case studies of Tonkin 2 and TestBed 2, however, indicate that the relatively thin exterior wall sections allow

Table 5.2: Comparative Surface Temperatures of Building Materials measured

Surface Material		Time & Date	Temperatures
Metal		05.08.2024; 13:00	
Corrugated sheet metal - red	(1)		88,4 °C
Corrugated sheet metal - grey	(2)		89,8 °C
Corrugated sheet metal - green	(3)		71,2 °C
Corrugated sheet metal - blue	(4)		80,1 °C
Ceramic		05.08.2024; 13:00	
Terracotta red - unshaded	(5)		66,2 °C
Terracotta red - shaded	(6)		32,8 °C
Grass		02.05.2025; 13:00	
Artificial turf	(7)		74,2 °C
Natural grass	(8)		36,6 °C
Vegetation TB2		10.08.2024; 12:30	
Leaf surface	(9)		54,4 °C
Indoors TB2			
South-facing window frame	(10)	02.05.2025; 14:00	32,3 °C
West-facing exterior wall	(11)	02.05.2025; 21:30	33,1 °C
Urban fabric baseline			
Roof top surfaces	(12)	10.08.2024; 12:30	51,2 °C



heat to be transmitted rapidly to the interior. Thermally, the constructed exterior walls perform similarly to internal partitions and therefore provide little resistance as a protective outer skin.

Interior measurements of window panes and frames further revealed thermal discontinuities. While the window glazing consists of double-layered tempered glass, the aluminium frame (Xingfa, China) is non-insulated and installed directly into 130-150 mm masonry without a thermal break. As a result, solar heat readily penetrates through the frame into the interior, even though the glass itself reduces radiant heat gain. The masonry, in turn, absorbs ambient and direct solar heat throughout the day and releases it radially into both interior and exterior spaces during the cooler nighttime hours. Following Table 5.3 evaluates the standard U-value for one square meter of identical exterior wall for Tonkin 2 and Testbed 2.

Table 5.3: U-value Evaluation for one Square Meter

Component	Thickness (m)	Thermal Conductivity λ (W/m·K)	Thermal Resistance R_0 (m ² K/W)	U-Value (W/m ² K)
Single-layer wall, cement rendered (150 mm)	0,150	0,58	0,430	2,33
Double-layer tempered glass, (2 × 8 mm + film)	0,016	0,78	0,189	5,22
Aluminium frame, uninsulated (1.8 mm material thickness)	0,0018	220,00	0,170	5,88
Total U-value				13,425
Total R₀-value			0,789	

R-values include standard internal ($R_{si} = 0.13 \text{ m}^2\text{K/W}$) and external ($R_{se} = 0.04 \text{ m}^2\text{K/W}$) surface resistances in the calculation of *U*-values.

$$U = \frac{1}{R_{si} + \frac{d}{\lambda} + R_{se}}$$

$$R_{0wall} = 0.13 + \frac{0.15}{0.58} + 0.04 = 0.43 \text{ m}^2\text{K/W}$$

$$R_{0window} = 0.13 + \frac{0.016}{0.78} + 0.04 = 0.189 \text{ m}^2\text{K/W}$$

$$R_{0frame} = 0.13 + \frac{0.0018}{0.220} + 0.04 = 0.17 \text{ m}^2\text{K/W}$$

The calculated overall U-value of 13.425 W/m²K is substantially higher than the QCVN 09:2017/BXD reference limit of 2.38 W/m²K, indicating pronounced heat transfer into the building. In other words the facade is acting as radiator on both sides to the exterior and interior. The corresponding thermal resistance of 0.789 m²K/W aligns closely with the normative target range, although values above 1.0 m²K/W would denote improved thermal performance and resilience factors for the building itself.

Thermal focus on vegetated and non-vegetated facade sections:

Table 5.4 presents data from the sensor installations on the south- and west-facing facades of TestBed 2, differentiating between vegetated and non-vegetated sections. On the west side, the green façade had to be installed with a reduced offset of 250 mm from the exterior wall due to the dense urban setting and privacy constraints with neighbouring properties. This limited depth left the west façade more directly exposed to solar heat gain. By contrast, the system on the south side was implemented as planned with an 800 mm offset.

Measurements taken on 8 August 2024 indicate maximum temperature differences (ΔT) of up to 11 °C on both façades around 13:00, with the vegetated sections consistently outperforming the non-vegetated surfaces over the course of the day. Peak differences occurred between 15:30 and 16:00 on the west facade. This coincided with direct solar exposure, whereas on the south facade the maximum cooling effect appeared with a delay of approximately 2.5 hours. These results highlight the combined influence of orientation and vegetation offset on facade cooling performance. At the time of measurement, the vegetation was still relatively young, reaching approximately 2.5 m in vertical depth from the top edge.

Table 5.5 provides data from November 2024, three months later. Seasonal cooling reduced overall temperature differences compared to August, yet the same diurnal patterns of peak and delayed cooling were observed, with the vegetated sections continuing to outperform the non-vegetated reference.

Table 5.6 shows results from February 2025. Here, facade temperatures equalised at around 14:00, approximately 1-1.5 hours earlier than in the previous datasets. This shift reflects seasonal solar altitude and incidence angles under cooler climatic conditions in Hanoi. Peak temperature differences decreased to 3 °C on the west facade and 4 °C on the south facade. Nevertheless, the vegetated facade continued to demonstrate measurable thermal advantages and indicate concepts of building envelope shading as passive cooling.

Table 5.4: In-wall Temperatures of vegetated and non-vegetated Facades, Date 10.08.2024

Time (hrs)	West (blank)	West (Green, 250 mm)	Temp. (ΔT)	South (blank)	South (Green, 800 mm)	Temp. (ΔT)
00:00	33 °C	33 °C	0,0 °C	32 °C	33 °C	1,0 °C
02:00	31 °C	31 °C	0,0 °C	31 °C	32 °C	1,0 °C
04:00	31 °C	31 °C	0,0 °C	30 °C	31 °C	1,0 °C
06:00	30 °C	31 °C	1,0 °C	30 °C	31 °C	1,0 °C
08:00	32 °C	33 °C	1,0 °C	31 °C	31 °C	0,0 °C
09:00	35 °C	35 °C	0,0 °C	35 °C	32 °C	3 °C
10:00	39 °C	36 °C	3 °C	40 °C	33 °C	7 °C
11:00	43 °C	37 °C	6 °C	44 °C	34 °C	10 °C
12:00	46 °C	38 °C	8 °C	47 °C	36 °C	11 °C
13:00	49 °C	38 °C	11 °C	49 °C	38 °C	11 °C
14:00	49 °C	39 °C	10 °C	48 °C	39 °C	9 °C
15:00	49 °C	39 °C	10 °C	47 °C	39 °C	8 °C
15:30	50 °C	40 °C	10 °C	46 °C	40 °C	6 °C
16:00	47 °C	39 °C	8 °C	45 °C	40 °C	5 °C
17:00	45 °C	39 °C	6 °C	43 °C	39 °C	4 °C
18:00	43 °C	38 °C	5 °C	41 °C	39 °C	2 °C
20:00	38 °C	36 °C	2 °C	37 °C	37 °C	0,0 °C
22:00	34 °C	33 °C	1 °C	33 °C	34 °C	1,0 °C
24:00	33 °C	33 °C	0,0 °C	32 °C	33 °C	1,0 °C

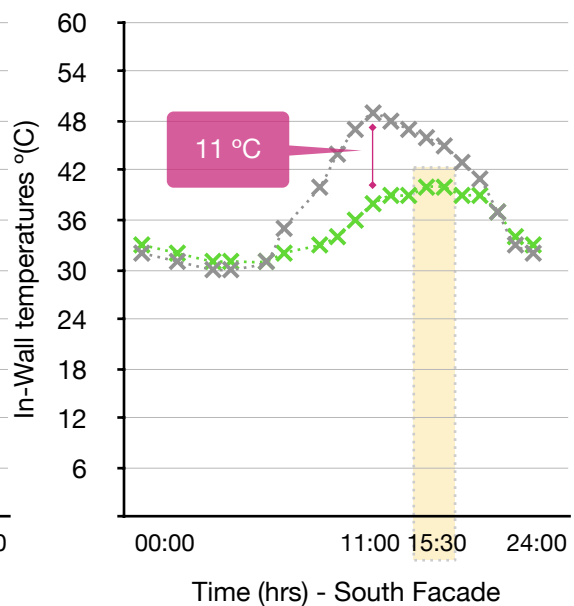
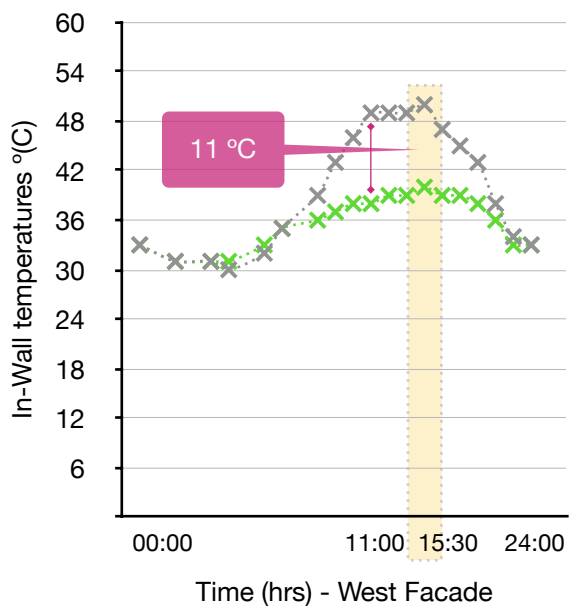


Table 5.5: In-wall Temperature of vegetated and non-vegetated Facades, Date 10.11.2024

Time (hrs)	West (blank)	West (Green, 250 mm)	Temp. (ΔT)	South (blank)	South (Green, 800 mm)	Temp. (ΔT)
00:00	24 °C	24 °C	0,0 °C	24 °C	26 °C	2,0 °C
02:00	23 °C	24 °C	1,0 °C	23 °C	25 °C	2,0 °C
04:00	22 °C	23 °C	1,0 °C	22 °C	24 °C	2,0 °C
06:00	21 °C	22 °C	1,0 °C	22 °C	24 °C	2,0 °C
08:00	24 °C	25 °C	1,0 °C	26 °C	24 °C	2 °C
09:00	27 °C	27 °C	0,0 °C	29 °C	25 °C	4 °C
10:00	31 °C	29 °C	2 °C	31 °C	27 °C	4 °C
11:00	35 °C	31 °C	4 °C	33 °C	29 °C	4 °C
12:00	39 °C	33 °C	6 °C	34 °C	31 °C	3 °C
13:00	42 °C	34 °C	8 °C	35 °C	32 °C	3 °C
14:00	42 °C	35 °C	7 °C	34 °C	33 °C	1 °C
15:00	43 °C	35 °C	8 °C	33 °C	34 °C	1,0 °C
15:30	41 °C	35 °C	6 °C	32 °C	34 °C	2,0 °C
16:00	38 °C	34 °C	4 °C	31 °C	33 °C	2,0 °C
17:00	35 °C	33 °C	2 °C	29 °C	32 °C	3,0 °C
18:00	32 °C	32 °C	0,0 °C	28 °C	32 °C	4,0 °C
20:00	29 °C	29 °C	0,0 °C	27 °C	30 °C	3,0 °C
22:00	27 °C	27 °C	0,0 °C	25 °C	28 °C	3,0 °C
24:00	25 °C	26 °C	1,0 °C	25 °C	27 °C	2,0 °C

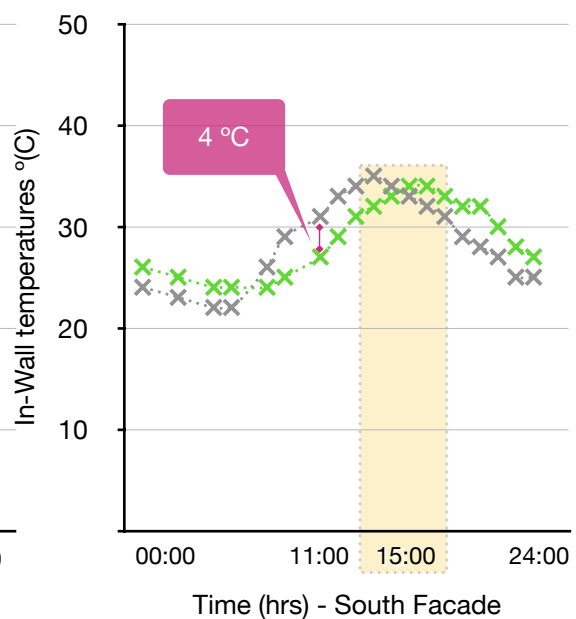
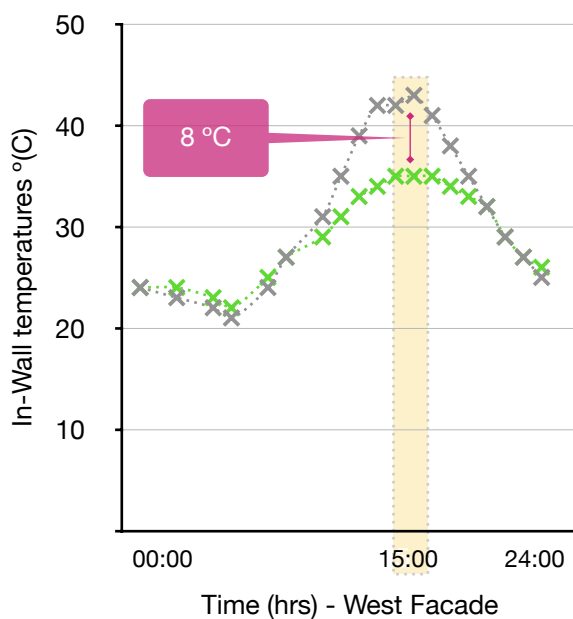


Table 5.6: In-wall Temperatures of vegetated and non-vegetated Facades, Date 10.02.2025

Time (hrs)	West (blank)	West (Green, 250 mm)	Temp. (ΔT)	South (blank)	South (Green, 800 mm)	Temp. (ΔT)
00:00	14 °C	15 °C	1,0 °C	14 °C	15 °C	1,0 °C
02:00	14 °C	15 °C	1,0 °C	14 °C	15 °C	1,0 °C
04:00	14 °C	14 °C	0,0 °C	14 °C	15 °C	1,0 °C
06:00	14 °C	14 °C	0,0 °C	14 °C	15 °C	1,0 °C
08:00	15 °C	15 °C	0,0 °C	15 °C	16 °C	1,0 °C
09:00	17 °C	16 °C	1 °C	16 °C	16 °C	0,0 °C
10:00	18 °C	17 °C	1 °C	18 °C	17 °C	1 °C
11:00	20 °C	18 °C	2 °C	20 °C	18 °C	2 °C
12:00	21 °C	19 °C	2 °C	21 °C	18 °C	3 °C
13:00	21 °C	19 °C	2 °C	21 °C	18 °C	3 °C
14:00	22 °C	19 °C	3 °C	22 °C	18 °C	4 °C
15:00	21 °C	19 °C	2 °C	21 °C	18 °C	3 °C
15:30	21 °C	19 °C	2 °C	21 °C	18 °C	3 °C
16:00	20 °C	19 °C	1 °C	20 °C	18 °C	2 °C
17:00	19 °C	18 °C	1 °C	18 °C	17 °C	1 °C
18:00	18 °C	18 °C	0,0 °C	17 °C	17 °C	0,0 °C
20:00	17 °C	17 °C	0,0 °C	16 °C	17 °C	1,0 °C
22:00	16 °C	17 °C	1,0 °C	16 °C	17 °C	1,0 °C
24:00	16 °C	16 °C	0,0 °C	16 °C	17 °C	1,0 °C

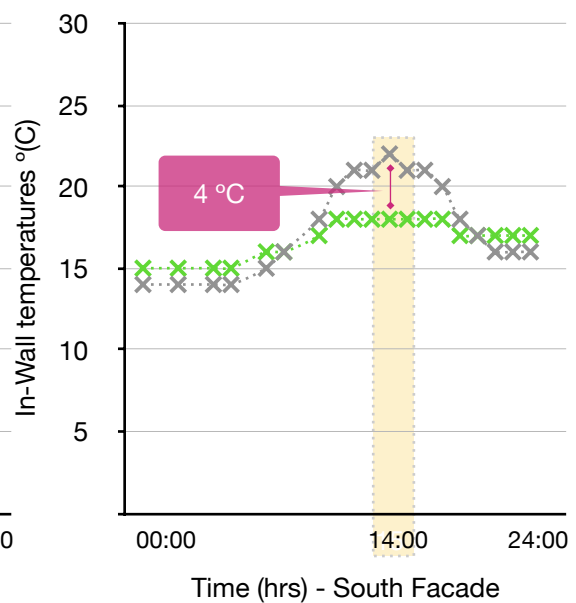
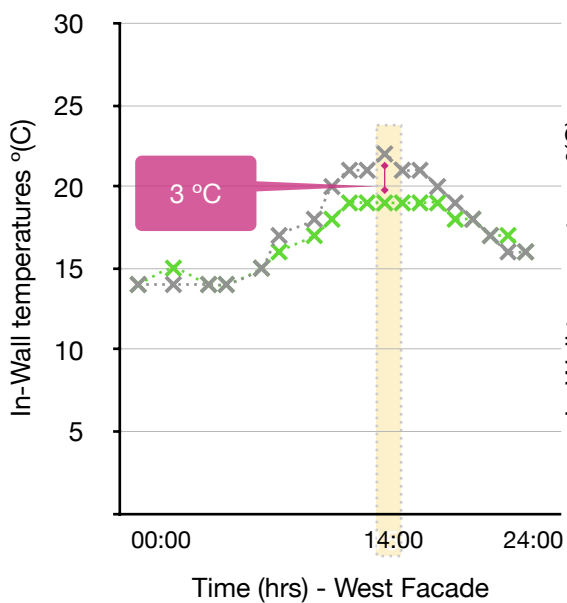
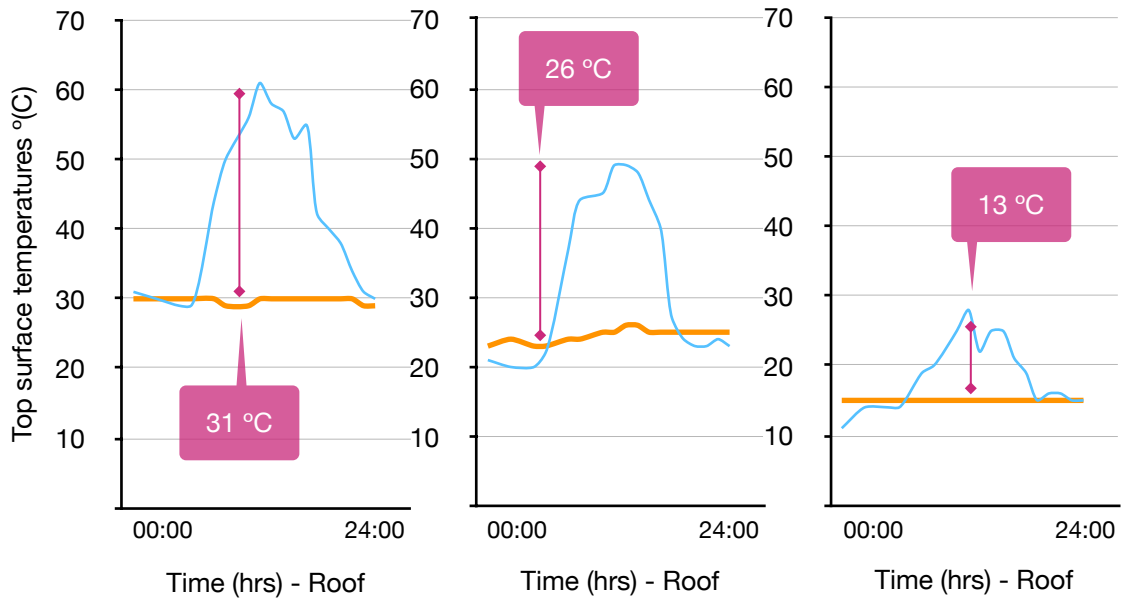


Table 5.7: Top-Surface Temperatures of Metal and Terracotta

Time (hrs)	Metal (green)	Terracotta (shaded)	Metal (green)	Terracotta (shaded)	Metal (green)	Terracotta (shaded)
Date	10.08.2024		10.11.2024		10.02.2025	
00:00	31 °C	30 °C	21 °C	23 °C	11 °C	15 °C
02:00	30 °C	30 °C	20 °C	24 °C	14 °C	15 °C
04:00	29 °C	30 °C	20 °C	23 °C	14 °C	15 °C
06:00	29 °C	30 °C	22 °C	23 °C	14 °C	15 °C
08:00	44 °C	30 °C	37 °C	24 °C	19 °C	15 °C
09:00	50 °C	29 °C	44 °C	24 °C	20 °C	15 °C
10:00	56 °C	29 °C	45 °C	25 °C	25 °C	15 °C
11:00	61 °C	30 °C	49 °C	25 °C	28 °C	15 °C
12:00	58 °C	30 °C	49 °C	26 °C	22 °C	15 °C
13:00	57 °C	30 °C	48 °C	26 °C	25 °C	15 °C
14:00	53 °C	30 °C	44 °C	25 °C	25 °C	15 °C
15:00	55 °C	30 °C	40 °C	25 °C	21 °C	15 °C
16:00	42 °C	30 °C	27 °C	25 °C	19 °C	15 °C
17:00	40 °C	30 °C	24 °C	25 °C	15 °C	15 °C
18:00	38 °C	30 °C	23 °C	25 °C	16 °C	15 °C
20:00	34 °C	30 °C	23 °C	25 °C	16 °C	15 °C
22:00	31 °C	29 °C	24 °C	24 °C	15 °C	15 °C
24:00	30 °C	29 °C	23 °C	24 °C	15 °C	15 °C



Thermal focus on roof top-surface materials and vegetation:

At least Table 5.7 presents temperature data from a sensor mounted on the green sheet-metal sandwich panel (50 mm) covering part of the roof area, and from another sensor placed on top of the terracotta tiles beneath plant containers A and B. Measurements were taken on 10 August 2024, 10 November 2024, and 10 February 2025. Notable are the peak surface temperatures of the sheet metal, which consistently occur around 11:00 in the morning across all three periods, shifting only seasonally in absolute value. During the early morning hours (00:00–06:00), the sheet metal cools to levels below the terracotta tile surface. By contrast, the terracotta tiles on the flat roof remain relatively stable throughout the year, levelling at approximately 30 °C in summer, 25 °C in autumn, and 15 °C in winter. Particularly striking is the near-constant halving of surface temperatures between the exposed sheet metal panel and the shaded terracotta beneath the plant containers. Continuous shading of the tiles plays a crucial role in this process and highlights the importance of shading as a strategy to reduce solar heat gain through the building envelope. This effect becomes even clearer when compared with Table 5.2 unshaded terracotta tiles reached peak values of 66.2 °C, again showing a near-halving of surface temperature under shading conditions. These results underline the role of rooftop shading systems as effective passive cooling strategies, offering valuable implications for roof design in tropical urban contexts.

Across the various measurements, several recurring patterns can be identified. First, surface materials strongly influence thermal behaviour, with coloured corrugated sheet metal and terracotta tiles reaching extreme peak values above 50 °C, while shaded or vegetated surfaces consistently show moderated conditions. Second, facade greening provides measurable cooling benefits of up to 11 °C, though performance varies by orientation, distance from the wall, and seasonal solar altitude. Third, thermal bridges in walls, windows, and frames demonstrate how insufficient construction quality amplifies internal cooling demands, leading to prolonged use of air conditioning systems. Finally, the comparison of vegetated versus non-vegetated surfaces confirms that shading and material choices interact directly. Taken together, these patterns underline that building envelopes in dense urban settings act as critical mediators between solar heat input, material properties, and indoor comfort. Finally, from mid-November 2024 onwards, technical issues began to occur, that sensor data increasingly disrupted until March 2025, when most units failed entirely. The failure could not be solved from remote distance. A detailed explanation of this issue is provided in Chapter 5.3.

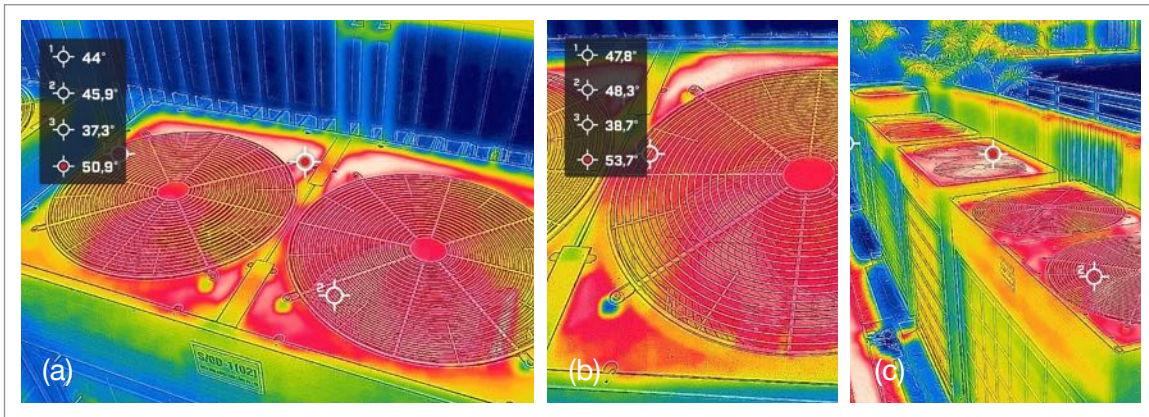


Figure 5.1: Thermal Imaging of AC Outdoor Units at Tonkin 2. (a) Twin Unit, (b) Top Surface Heat, (c) Top Outlets of AC Units

Reflections

Building envelope performance:

What does this concretely imply? First, it becomes evident that a shaded building envelope has a strong influence on the building fabric and, more importantly, that cooler exterior walls contribute significantly to indoor comfort. Qualitative inconsistencies in the thermal performance of the envelope, by contrast, result in increased cooling energy demand. Figuratively speaking, if the ‘skin’ is not consistently protected, it suffers thermal stress (‘sun burn’ effect) that must be ‘healed’ internally through intensified cooling. In building terms, this means that air-conditioning systems operate more frequently and for longer periods. Their exhaust heat, often exceeding 50 °C (Figure 5.1), is released into the surrounding environment, thereby elevating local ambient temperatures and aggravating urban heat stress. A thermally coherent envelope is therefore indispensable for a functioning system. Otherwise, gaps in the facade - such as non-insulated aluminium window frames - lead to unnecessary energy losses. These frames act, in effect, as radiators, conducting heat directly into the indoor environment. Under such conditions, the concept of the building as an adaptive node - dynamically interacting with its surroundings - cannot be realised. In contrary it underpins the common sense of thin exterior walls as method to led heat inside and try to release them through a ‘pushing back’ method by air conditioning usage.

Experience in the tropics:

The results obtained through thermal imaging, supported by the embedded wall sensors, stand in contrast to the Vietnamese building code *QCVN 09:2017/BXD* for energy-efficient buildings. In particular, high-rise construction in tropical climates

should address passive cooling and shading strategies more thoroughly. As an early pioneer, Ken Yeang (Yeang, 1996, 2006) has explored such approaches in Malaysia for decades, many of which are transferable to Vietnam given the climatic similarities between the two countries. Adaptive advantages could be leveraged to design high-rises that contribute not only to their own passive cooling but also exert a positive impact on the immediate microclimate. Recent studies underline that facade adaptation and design play a critical role in reducing urban heat islands (UHI) (Ornam, 2024). Likewise, investigations in Singapore have demonstrated that cool wall strategies and reduced cooling loads from air-conditioning systems can significantly improve thermal resilience in tropical conditions (Nazarian et al., 2019).

Site Note: Colour Perception and Thermal Performance:

An aspect in the discussion of urban heat is the understanding of colour in relation to material energy and surface temperature. The author encountered this topic in exchanges with engineers and in lecturing practice, where it became evident that colour choices for building products are often shaped by symbolic or cultural reasoning rather than by thermal performance. Although this remark can only be made in passing here, it highlights a clear research gap: despite its practical relevance for construction and urban planning, systematic scientific investigation of colour-specific thermal effects in roofing materials remains scarce.

Thermographic surveys in Hanoi confirmed that average surface temperatures of up to 51.2 °C (Table. 5.2) can be reached on hot days. The extensive use of coloured corrugated metal sheets - commonly in red, green, blue, or grey - intensifies local heat absorption and contributes to urban heat islands. By lowering the albedo of the built environment, these materials in contrast amplify heat stress for residents and workers. Figure 5.2 illustrates this relationship by juxtaposing (a) the classical colour wheel and its primary, secondary and tertiary colours²⁸, that split the circle of colour into halves of warm and cold colour tones. The colour recognition scale of the thermal camera used is shown in (b), and (c) the symbolic Feng Shui (Phong Thuy) compass, in which blue represents the north, water, and coldness. In Vietnam, such associations are common knowledge as reasons for the widespread use of blue sheet-metal roofs in urban and industrial settings. However, this narrative is misleading: the thermal load of coloured materials is not determined by symbolic attributes but by physical properties of solar absorption and reflection. Therefore they stay in stark contrast. White surfaces exhibit the highest reflectance, whereas black absorbs the most. In short, light colours perform as 'cool' surfaces, while dark or saturated colours - commonly perceived as 'cold' - often reach the highest surface temperatures, effectively acting as 'hot'

²⁸ <https://www.youtube.com/watch?v=pnu0Z43HrMg> (09.10.2024)

colours (d). This inversion is confirmed by the results in Table 5.2, where coloured sheet metals record the highest thermal values, reaching nearly 90 degrees Celsius. In the literature on roofing and heat islands, cool roofs^{29,30} with high solar reflectance are consistently shown to reduce cooling energy demand and mitigate ambient heat stress. By contrast, conventional coloured sheet-metal claddings (red, blue, green) have low solar reflectance index (SRI) values and significantly increase solar heat gain in hot climates. While reflective coatings can improve performance, their efficacy diminishes over time in tropical conditions. Scientific attention has focused primarily on white or light coatings, leaving a research gap regarding the thermal behaviour of coloured roofing materials that are prevalent in cities of the Global South. This issue deserves further study, as arguments grounded solely in traditional or symbolic interpretations of colour are increasingly inadequate under conditions of climate change and urban densification.

Limitations of thermal imaging in the study:

Limitations in surface measurement lie in the use of the FLIR ONE PRO thermal camera. The camera delivers reliable data that compares well with professional-grade devices. Far greater challenges arose in terms of access to buildings and apartments, where access from the building management is always required.

Building envelopes were mostly photographed from street level. Mounting thermal cameras on unmanned aerial vehicles (UAV) would represent the most advanced approach, allowing for perpendicular recordings of facade and thus more accurate results. In this study, the method to capture facades from various elevations, using vantage points such as other buildings, balconies, parking structures, and other locations that improved the angle of view was applied to most situations. Nevertheless, most recordings were taken from street level or flat rooftops. Deviations in accuracy due to distance from the surface were mitigated by taking multiple recordings from different points. The fact that the camera tended to overheat at high outdoor temperatures, leading to occasional interruptions, did not compromise the overall quality of the results. Thermal recordings were further constrained by the limited time frame of on-site visits, meaning that a continuous year-round observation of the facades could not be achieved. By contrast, the installed sensor network provided continuous 24/7 operation in the beginning.

²⁹ https://www.aceee.org/files/proceedings/2004/data/papers/SS04_Panel1_Paper01.pdf (10.10.2024)

³⁰ <https://www.mdpi.com/2075-5309/15/5/685> (20.08.2025)

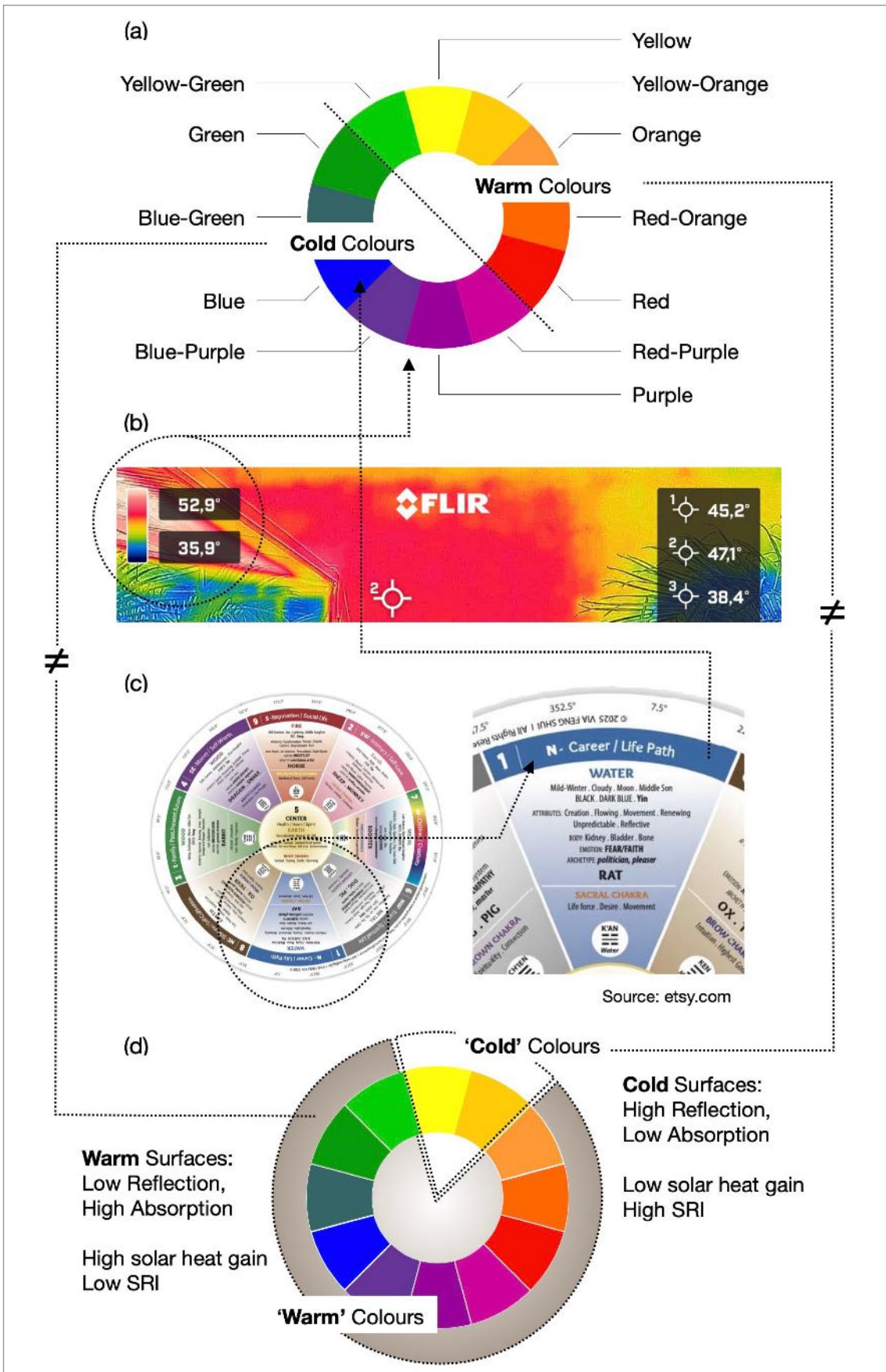


Figure 5.2: Colour Perception and Thermal Performance through different Lenses: (a) Colour Wheel, (b) Thermal Camera View, (c) Feng Shui Wheel, (d) Thermal Performance

5.2 Building Envelope Parameters - Results and Reflections

The empirical analyses of the Tonkin 2 building envelope, presented in Chapter 4, provide the basis for a critical discussion of material characteristics, construction practices, and performance outcomes. By examining parameters such as the wall-to-window ratio (WWR), the brick-to-concrete ratio (BCR), and the one-square-meter reference wall section, quantifiable insights into thermal performance through building materials can be derived. These findings not only highlight the technical qualities of the as-built structure but also reveal systemic inefficiencies, such as elevated U-values, inconsistent construction, and limited adaptation to climatic stressors. The following findings and reflections contextualise these results within economic, regulatory, and sustainability frameworks, serving as a bridge to broader considerations of resilience and adaptive capacity in the subsequent chapter.

Results

Geometry of the residential tower Tonkin 2 (Twin of Tonkin 1):

The assessment of the building envelope begins with its geometrical parameters, expressed through the wall-to-window ratio (WWR) and the brick-to-concrete ratio (BCR). Both indices are commonly applied in evaluating energy performance, since higher shares of glazing generally lead to increased heat gain and cooling demand. In the case of Tonkin 2, the calculated WWR of 59/41 indicates a smaller proportion of facade glazing compared with rendered wall sections. The installed glazing in doors and windows consists of a three-layer composite of 4 mm glass + 0.38 mm polyvinyl butyral (PVB) interlayer + 4 mm glass, summing to 8.38 mm in total, mounted in uninsulated aluminium frames. The specific weight of 25 kg/m² at 10 mm thickness can serve as a calculation reference. In the case of Tonkin 2, the weight is 20 kg/m², with the thin PVB interlayer disregarded. The aluminium frame is withdrawn with 8% of the overall glazing weight. Thermal investigations revealed that the aluminium frames of windows and doors act as radiators, transferring heat into the building, while air-conditioning units attempt to maintain indoor comfort levels. Thermal bridges occur particularly at the aluminium frames of the windows and the diagonally positioned bricks mentioned in chapter 4.3.4. It should therefore be considered either to install insulated frame systems or to reduce the overall window surface.

On-site observations further demonstrated that most residents keep curtains or blinds permanently closed in order to limit daylight and heat entry. As a result, higher reliance on artificial lighting indoors must be assumed. It should also be noted that thermal loads are already present within the building interior before mitigation is attempted. This behaviour reduces the intended advantages of large window surfaces, while their

disadvantages in terms of heat transfer and cooling demand remain.

For the brick-to-concrete ratio (BCR), a distribution of 44/56 was identified, indicating a higher proportion of concrete compared with masonry in the façade. Conventional brickwork, as applied in Tonkin 2 and TestBed 2, stores heat over extended periods and subsequently releases it back indoors. The principle remains: heat must be kept outside, coolness retained inside. In building physics, this is often achievable only through more massive wall sections that properly interlock with the slab edges. Preliminary inspections, however, revealed execution gaps at slab junctions, indicating a limited appreciation of the functional role of the wall.

Given that walls play an essential role in the thermal cycle of a building, a comparative analysis at the scale of one square meter was undertaken to identify potential improvements in thermal performance. Walls only form a homogeneous building envelope when they are flush with the slabs. Three typical masonry solutions - single brick (B1), double brick (B2, in line with prevailing standards), and autoclaved aerated concrete (AAC) - were compared with respect to thermal performance, material density and weight, embodied CO₂ emissions, and economic cost. The results indicate that the shift from single to double brick provides measurable improvements in U-value and indoor comfort, albeit at the expense of increased material consumption and structural loads. By contrast, AAC presents an alternative with a suitable balance of insulation capacity and weight, while also offering potential for emission reductions compared to conventional brick masonry. Figure 5.3 illustrates three wall types: (a) traditional brickwork, (b) AAC block construction, and (c) an advanced clay-based brick block system currently available in Europe. The comparison highlights the impact of thermal conductivity, underlining the common observation that a reduction in cement joints enhances thermal resistance. The more homogeneous the wall structure between floor slabs, the more effectively solar heat gains is been prevented. Ergo, less joints are key factors for building envelope resilience.

Although wall types (a) and (c) are both developed from the same natural resource - clay - they differ fundamentally in thermal behaviour but proof the natural qualities of clay based building materials if considering applied technology. The main function of the building envelope is to block external heat transfer and to manage internally generated heat loads from occupants and technical equipment besides moisture, meanwhile maintaining indoor cooling for comfort living. In the case of traditionally fired bricks, external heat diffuses into the building fabric through the brick and cement joints while the brick masonry stores the radiation over a longer period. with equal pace as seen in Tables 5.4-5.6. In addition the following Table 5.8 summarises the comparative values (Appendix A.2) and forms the basis for subsequent reflection on envelope performance, cost implications, and ecological footprint. However, it is

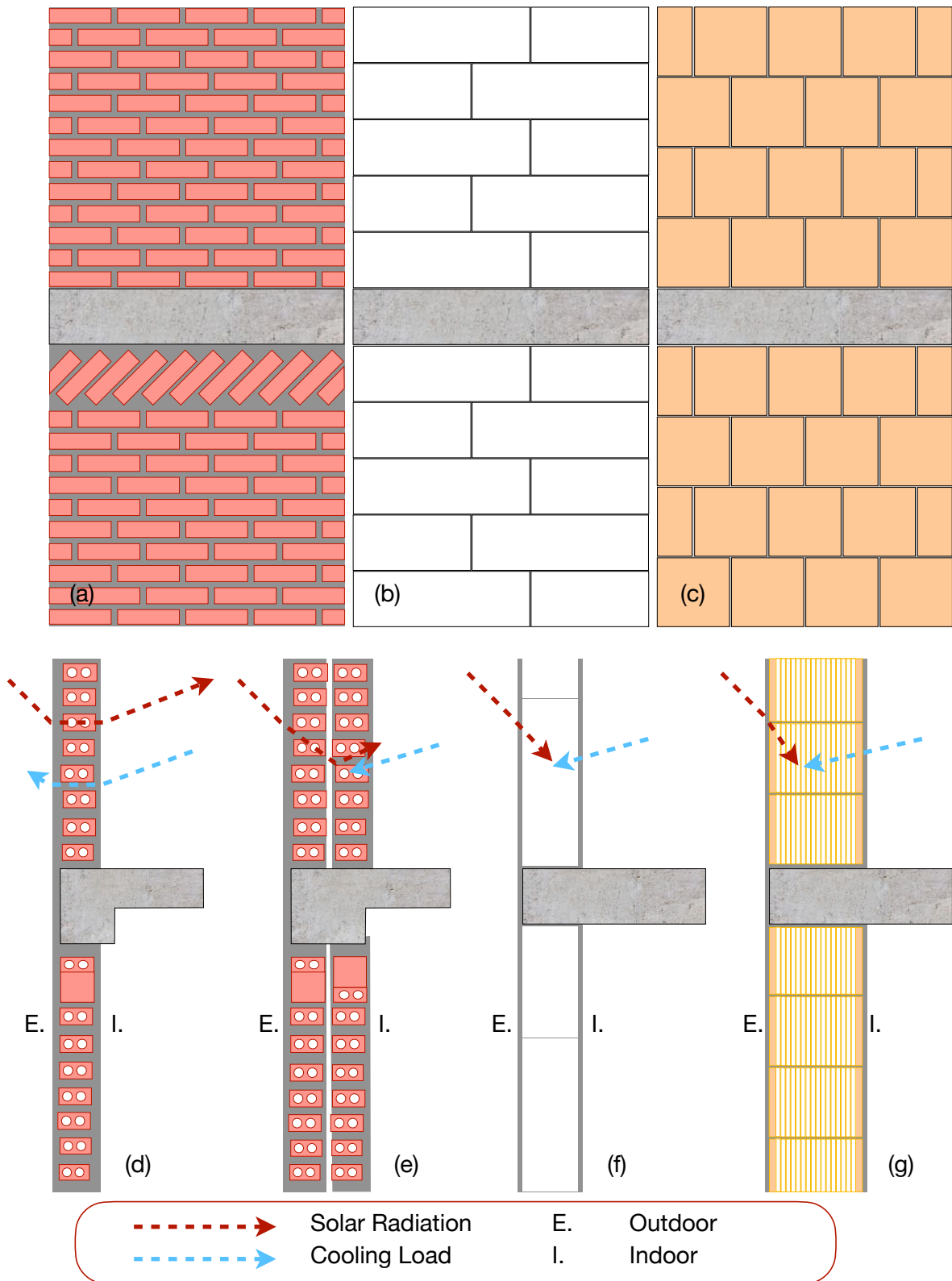
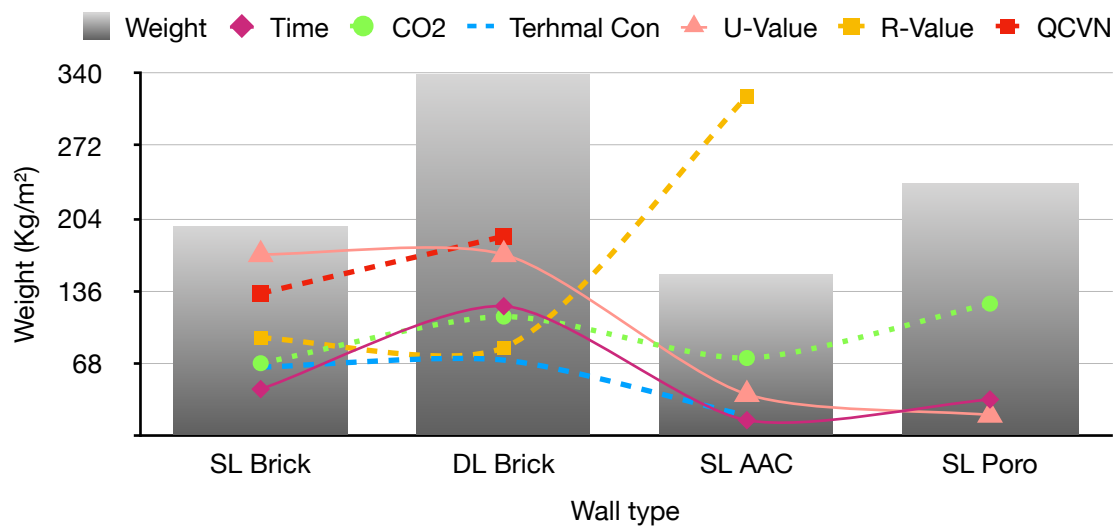


Figure 5.3: Schematic Wall Masonry Elevation in Transition to reinforced Concrete Slab / Beam (a) traditional Brick (as built), (b) AAC Block, (c) Poroton Brick Block; and exterior Wall Sections (d) single Layer Brick 150 mm (as built), (e) double Layer Brick 240 mm (required by Regulation), (f) AAC Wall 200 mm and (g) Poroton Brick Block 365 mm

Table 5.8: Comparative Wall Material Parameters (per m² of Wall Area)

Parameter	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer	Poroton Single Layer
Material & Dimensions					
Dimension	mm	210/100/55	210/100/55	200/200/600	248/365/249
Weight	Kg	1.3-1.5	1.3-1.5	15.6	13,5
Material	-	Clay	Clay	Autoclaved Aerated Concrete	Clay
Thermal conductivity λ	W/mK	0.7	0.7	0.16	0.08
U-Value	W/m ² K	2.65	2.92	0.77	
R-Value	m ² K/W	0.38	0.34	1.31	
Consumption & Weight					
Bricks	pcs	56.60	113	9	16
Weight	Kg/m ²	197.24	339.25	151.80	236.6
Construction time (min)*					
Total	min	180	500	60	140
* time including laying brick and plastering surface					
Life Cycle Assessment (LCA)					
Total	kg CO ₂ e/m ²	28	46	30	51



misleading to assume that absorbed heat is released outward again.

Wall type performances

At the smallest unit of analysis - one square meter of wall - preliminary assumptions can already be drawn for the entire Tonkin 2 building envelope, which, as the 'skin', is intended to protect the structure. The regulatory benchmark is the national building standard QCVN 09:2017/BXD. The weight difference between the lightest and heaviest wall type is significant at 187 kg, with the AAC block wall representing the lightest configuration and the double brick wall the heaviest. It is important to note that both the double brick wall (DL Brick), the AAC wall (SL AAC), and, by way of comparison, the Poroton wall (SL Poro) are defined as external walls, whereas the single layered brick wall (SL Brick) act as typical interior partition.

When parameters such as U-value, R-value, installation and curing time, and unit count are considered, the AAC block wall clearly outperforms, particularly in terms of thermal transmittance (U-value) and thermal resistance (R-value). These values are crucial indicators of the quality of the building envelope, which, as outlined earlier, functions as the building's largest organ, shielding it most directly from external climatic influences and solar radiation. With regard to embodied CO₂ emissions, the differences between wall types are less pronounced, clustering around an average of 38.75 kg CO₂e/m². Poroton, introduced here as an example of a clay-based construction material, lay in the middle of comparison in terms of weight but demonstrates excellent thermal performance. Since Poroton is not available in Vietnam, it is excluded from further analyses, though it can be regarded as a development potential for the domestic brick industry to modernise production and replace outdated clay presses.

Focusing on the three wall types listed in QCVN 09:2017/BXD, AAC surpasses both brick variants across all categories except embodied CO₂ emissions. Moreover, strict compliance with standards would prohibit the use of SL Brick as an external wall due to its excessive solar heat gain. Construction speed is another important factor in high-rise building construction. Here again, AAC proves superior, primarily due to its larger format: only nine AAC blocks are required per square meter, compared to 56.6 for SL Brick and 113 for DL Brick. AAC also offers practical handling advantages, being easy to cut and place. In addition, its thin-bed adhesive technique outperforms the traditional thick-bed mortar method, which requires on-site mixing and moistening of each brick. Another factor lies in the production tolerances of building materials. Traditional bricks often deviate 8 - 10 mm from nominal dimensions, resulting in uneven wall surfaces even when properly aligned. Subsequent plastering compensates for these irregularities, producing layer thicknesses that frequently exceed standards (Figure 5.4).



Figure 5.4: (a) Brick Masonry - Transition to Beam, (b) DL Brick cut, Air Gab visible, (c) DL Brick broken, (d) Thickness Plaster Layer, (e) Brick Deviation and (f) AAC Wall Type

In contrast, AAC and Poroton exhibit tolerances within ± 1 mm. When laid in thin-bed adhesive with a maximum joint thickness of 3 mm, the system creates a homogeneous wall with very good thermal properties and equal surfaces. Consequently, plaster layers remain in the Millimeter rather than Centimeter range. Taken together, these aspects of weight differences, inferior performance, and longer construction times associated with traditional brick walls led imagine about upscaling those measures to the T2 building and in further step to the entire high-rises of the Vinhomes Smart City Hanoi.

Upscaling findings to the research building T2:

Building on the one-square-meter analysis, the following step applies the parameters to the brick-to-concrete ratio (BCR) value of 9.796 m² of masonry facade at Tonkin 2. The resulting quantities shift considerably. In terms of weight, there is a difference of approximately 500 tonnes between the AAC wall and the single-layer brick wall. This additional load is comparable to the mass of the entire technical building equipment installed in and on the case study building. The effect can be visualised as a backpack carried by a hiker - clearly perceptible in structural terms. The difference becomes even more obvious when comparing AAC with the double-layer brick wall, which

Table 5.9: Scaled Parameters on T2 related to BCR (9.796 m²)

Parameters	Unit	SL Brick (B1)	DL Brick (B2)	SL AAC
Material weight				
Total	Tsd (t)	1.932	3.323	1.487
Construction time per one labor				
Total	yrs	3	9	1
CO2 emission				
Total	kg CO ₂ e/m ²	11.120	18.723	6.925
Payloads				
Total	pl	1.074	1.682	144

**Table 5.10: Scaled Parameters on VSC High-Rise Buildings**

Parameters	Unit	SL Brick (B1)	DL Brick (B2)	SL AAC
Material weight				
Total	Tsd (t)	115.930	199.398	89.222
Construction time				
Total	yrs	202	561	67
CO2 emission				
Total	kg CO ₂ e/m ²	667.202	1.123.400	414.900
Payloads				
Total	pl	64.441	100.897	8.622



qualifies as a proper external wall: here, a potential weight reduction of around 1,000 tonnes can be identified. These disparities extend consistently across other

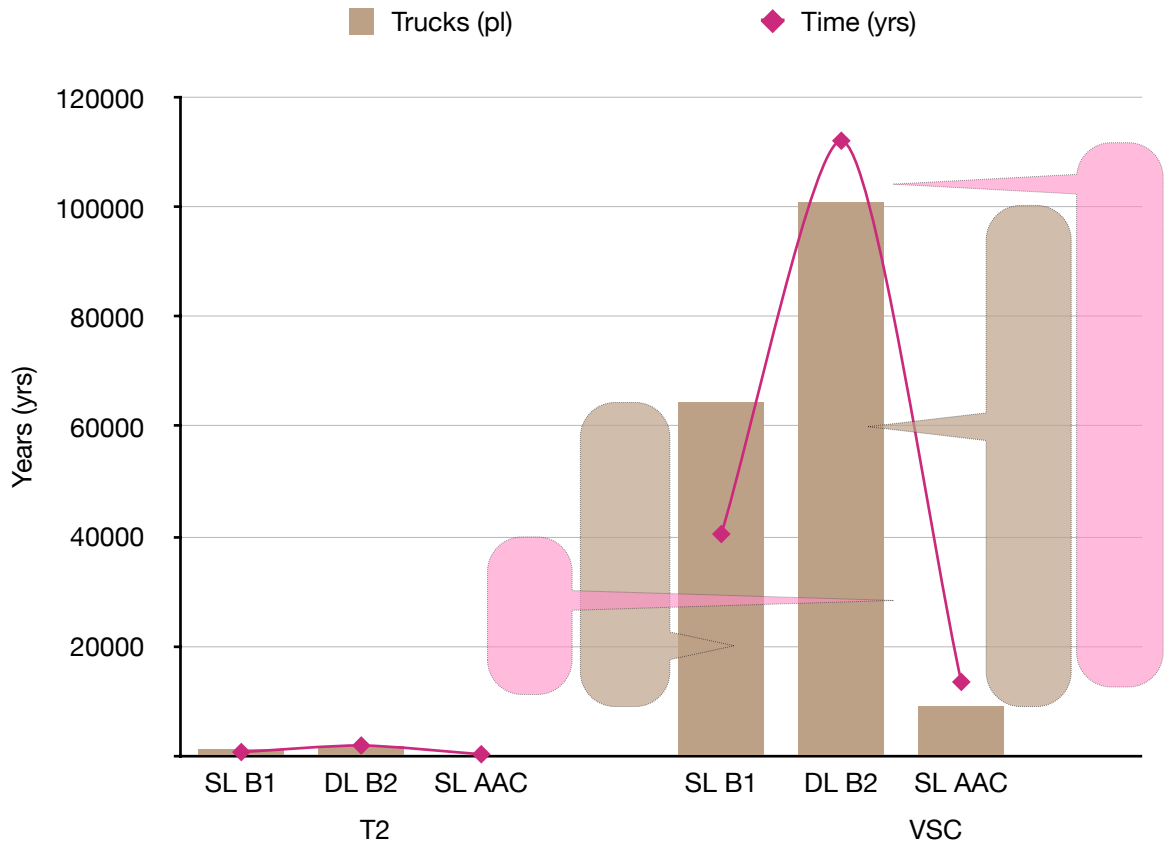
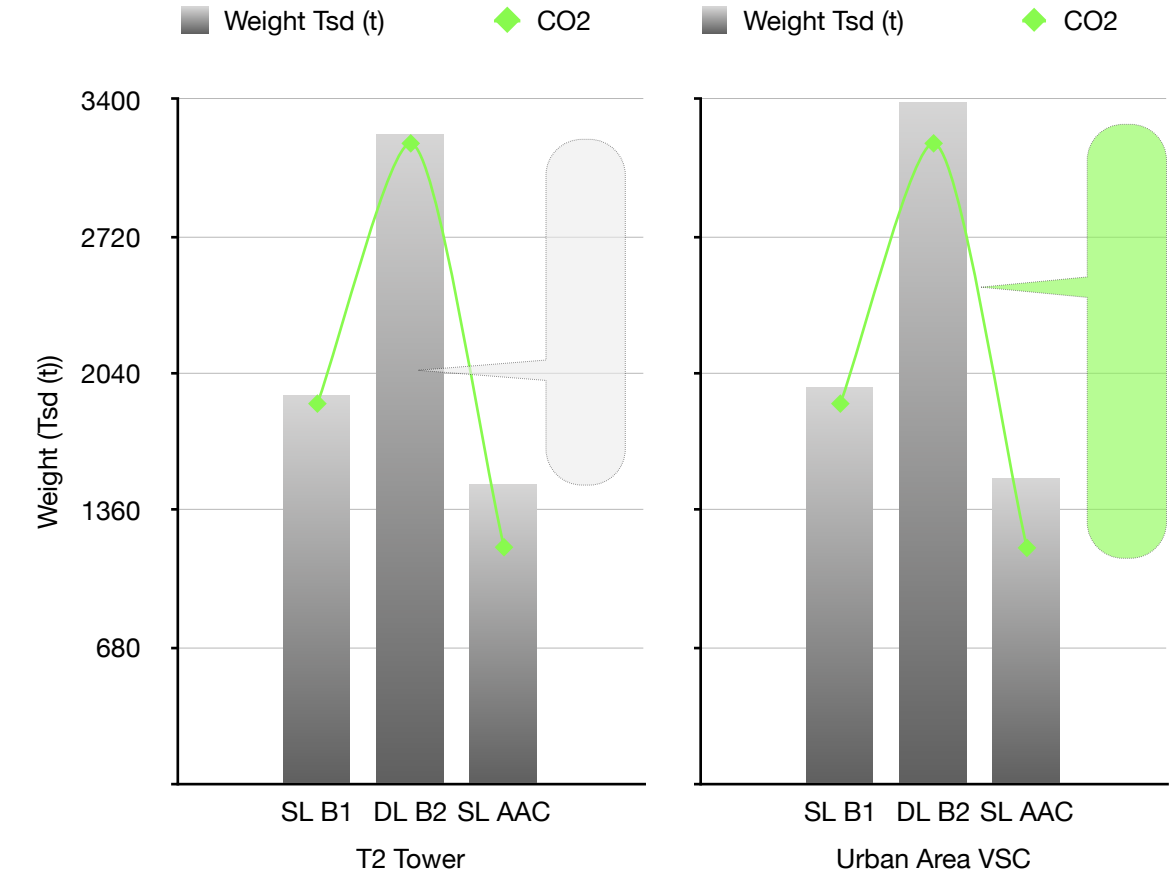
parameters such as construction time and emissions as seen in Table 5.9 and in more detail in appendix A.2. For example, when expressed as cumulative construction weeks, AAC achieves an advantage of nearly 500 weeks over the single-layer brick wall, and about 1,500 weeks compared with the double-layer brick wall. In Vietnam, the effect is partially offset by the widespread reliance on low-cost labour, with large workforces compensating for inefficiencies in wall assembly. It must also be noted that the construction industry is in continuous transformation, with incremental improvements observable from site to site, particularly in safety measures and logistics. A further dimension of this comparison emerges in transport requirements. Using a standard 30-ton and five axle truck as reference, the calculated number of deliveries diverges sharply: 1,074 trips for single-layer brick, 1,682 trips for double-layer brick, and only 144 trips for AAC. These differences carry direct implications for sustainability considerations - not only through the reduction of transport-related CO₂ emissions, which are modest per trip but accumulate substantially - but also through procurement costs, which are strongly influenced by logistics.

Upscaling to VSC Hanoi:

When taken the values identified above and extrapolated to all high-rise buildings of the VSC, which combined are 60 towers in total, the results increase dramatically and more visible. This cumulative calculation is feasible because the buildings follow highly standardised construction principles; their architecture is largely identical and marginally varied. It should be noted that these calculations are traceable back to the square-meter scale made by one labour, and thus to individual bricks and goods delivered in 25 kg sacks. More precise data is hardly available due to confidentiality constraints. Appendix A.2 provides more detailed calculations and in extend calculation of payloads.

In summary, it can be stated that, for instance, approximately 27 million tons of masonry can be saved when comparing AAC to the single-layer brick wall. In relation to the double-layer external brick wall, AAC demonstrates potential material savings of nearly 110 million tonnes that represents nearly 46% resource savings as visible seen in table 5.11. The CO₂ emission savings are similar to that of weight and bond to the bricks, mortar and plaster. Further differences and similarities are clearly stated in Table 5.10, particularly under the parameter of payloads: AAC requires only 8,622 truckloads, which amounts to less than one-tenth of the over 100,000 trips necessary for double-layer brick walls. This provides evident opportunities for resource-efficient planning and execution of high-rise buildings. Even though many of these material transports are mitigated by the on-site provision of silos, which reduce delivery frequency, the environmental impacts of truck movements on the surrounding context

Table 5.11: T2 Comparison to VSC Resource Benefits



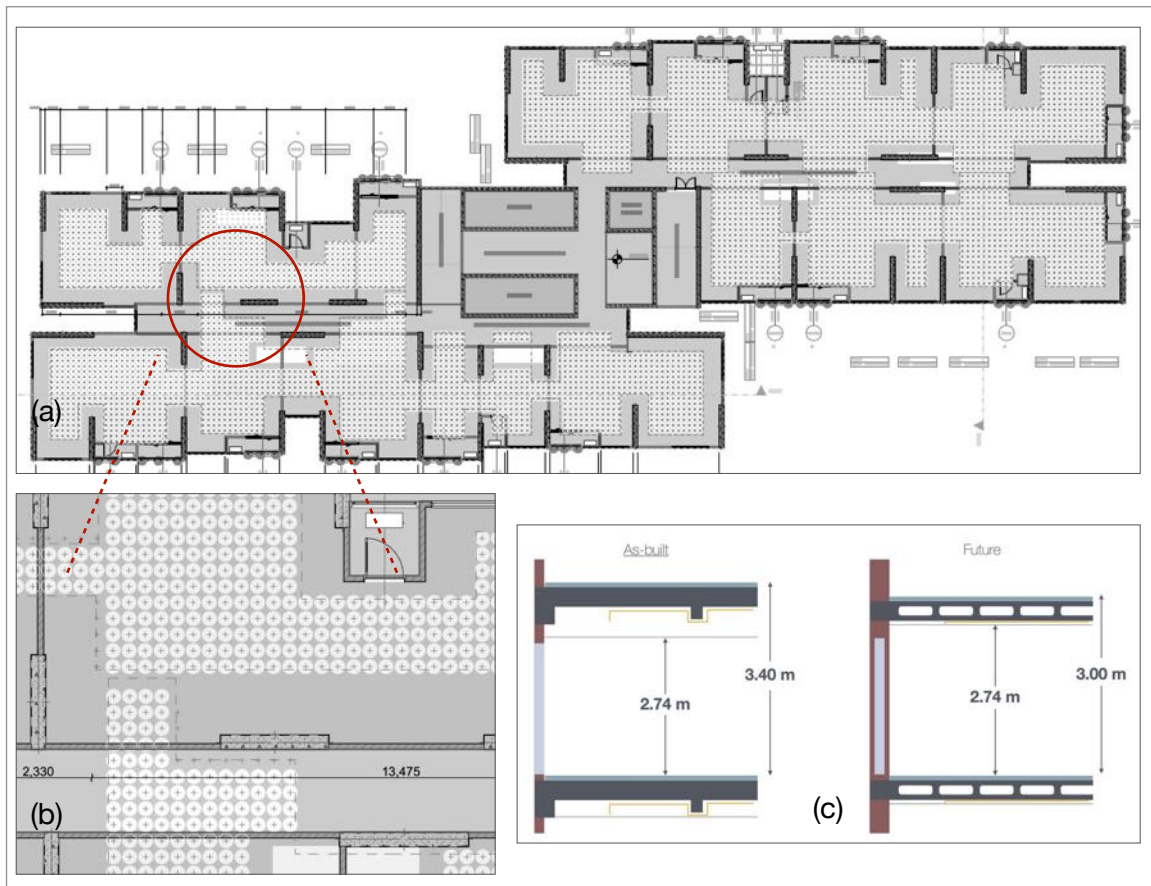


Figure 5.5: (a) Tonkin 2 Floor Plan with Concrete Spacers, (b) Zoom Concrete Spacer, (c) Slab Section before and after using Concrete Spacers

cannot be overlooked. AAC achieves an order-of-magnitude reduction in truck movements and time compared to double-layer brickwork, cutting required payloads by nearly 90%. This reinforces AAC's role as a resource-efficient wall material for high-rise construction in Vietnam's context in comparison to the thermal comparable double brick wall besides following regulations stated.

Following - apart from academia - a recent article in Nhan Dan³¹ from 7 January 2025, which projects urban districts in Vietnam to continue expand by over 44% in the coming years, questions of sustainable construction are gaining urgency. Holistic approaches, such as those outlined in this study, are therefore increasingly important for the implementation of urban districts - and particularly for "smart," resource-saving forms of construction and development. To keep a system of healthy high rise buildings

Performance and potentials for concrete resource saving:

To deepen the perspective on system resilience, it is necessary to look beyond the

³¹ <https://en.nhandan.vn/continuing-to-improve-urban-development-policies-post143082.html> (10.09.2025)

building envelope and consider the structural framework, specifically the reinforced concrete frame construction. This framework is dimensioned to transfer the loads of masonry and external forces into the structure with appropriate safety factors. Alongside optimisation potentials in the walls - whether material-related or thermal-technological innovations exist that can reduce concrete consumption while simultaneously improving construction quality, structural stability, and additional factors such as lowering CO₂ emissions.


One such innovation involves the use of concrete void formers, which are placed between the rebar layers to create hollow-core slabs instead of solid concrete decks. These reduce the overall weight of the building while increasing its stiffness. In Asia, the so-called U-Boot system (grid aligning 520 x 520 mm) has been established, though it is - as a standard - not yet widely applied in high-rise construction in Vietnam. Athira Anil and Vidya Jose³² review the advancements for U-Boot in Construction in India. In Europe, comparable technologies include BubbleDeck from the Netherlands and Unidome, a German product that has been in use for over a decade. The advantage of concrete spacers lie in eliminating the need for the downstand beams that are present in virtually every Vietnamese building to ensure structural stiffness. Their removal results in flat slabs functioning as surface load-bearing systems, thereby making downstand beams redundant.

For the present case study, the Unidome system was applied in the CAD and empirical simulation. For the Tonkin 2 residential tower, conservative calculations indicated concrete savings for slabs of 25% using Unidome XS60 (grid aligning 350 x 350 mm) that increases the overall slab thickness from currently 160 mm to 210 mm while subsequently reduces the amount of concrete for the overall construction by 16%. Another advantage of employing void formers is that buildings can be designed both lighter and lower in floor-to-floor height. In practical terms, this means that for every eight to ten standard floors, depending on the floor height, one additional floor could be structurally added (Figure 5.5). In the case of Tonkin 2, this would mean four to five additional floors. This has implications not only for the resource efficiency of the building but also for its economic viability, particularly regarding water management and resource reuse. From a marketing perspective, it also offers potential for higher profitability.

In this case study, the use of void formers was calculated to save up to 700 concrete mixer truck deliveries, corresponding to an additional 5 tonnes of CO₂ savings per building. From a holistic standpoint, such measures clearly demonstrate where optimisation levers can be adjusted to design, build, and operate buildings that are more resilient for the future. The calculations are not taking into account the reduced amount of rebars - while the manufacturer is estimating 20% in weight reduction.

³² <https://www.ijetajournal.org/volume-7/issue-6/IJETA-V7I6P2.pdf> (12.09.2025)

Table 5.12: Concrete Slab Resource Potentials for T2


Parameters	Unit		Volume
Material			
Currently	Metric (ton)		39.138
Reduction	Metric (ton)		6.250
Total	Metric (ton)		32.888
CO2 emission			
Currently	kg CO ₂ e/m ³		24.422
Reduction	kg CO₂e/m³		3.900
Total	kg CO ₂ e/m ³		20.522
Concrete Mixers			
			
Currently	pl		3.914
Reduction	pl		625
Total	pl		3.289

Instead the following table 5.12 and 5.13, accompanied by a graph, summarises the calculated parameters from Appendix A3.4 of T2 and extrapolates them to the high-rise cluster of VSC Hanoi, similar to the earlier example on wall materials. Overall resource potentials of reducing the consumption for Concrete, CO₂ emissions and subsequently reducing the amount of truck deliveries by 16%. Vinhomes, as the largest developer of new urban districts in Vietnam, typically manages 20-30 parallel projects in planning, each relatively consisting of clusters of high-rise towers, shophouses, villas, malls, schools, hospitals and further facilities. While these districts are broadly similar in design principles and alignment apart from local orientation, they highlight the scale at which urban development and densification take place. They also illustrate the magnitude of resources that could be used more efficiently through the application of the above-mentioned optimisation strategies.

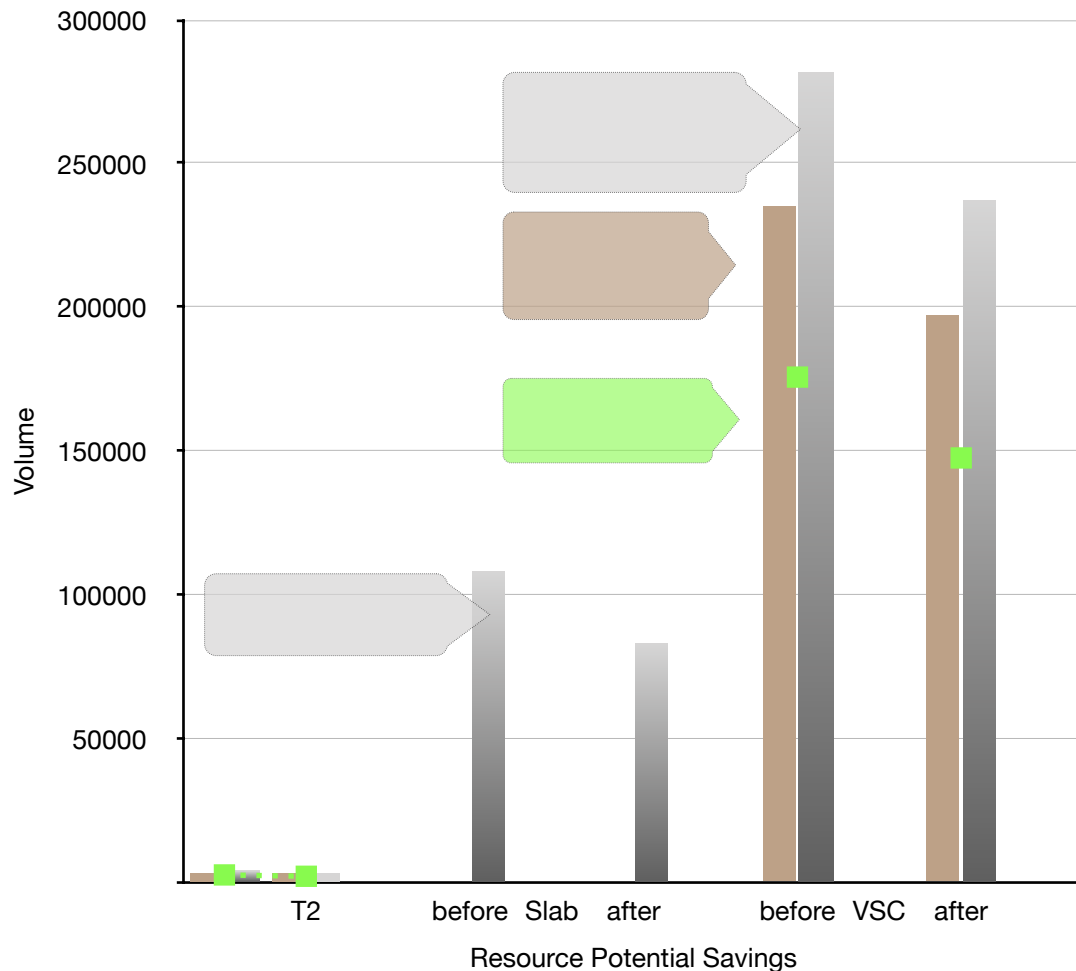
MEP weight impact on the building envelope :

In a final step, the building envelope of Tonkin 2 is examined in relation to its mechanical, electrical and plumbing (MEP) systems. Local developers such as Vinhomes are continuously striving to optimise water supply and cooling systems in their high-rise projects. In the case of the Smart City towers, and in their typologically identical counterparts, the majority of technical equipment is concentrated on the roof.

Table 5.13: Concrete Slab Resource Potentials for VSC

Parameters	Unit		Volume
Material			
Currently	Metric (ton)		2.348.274
Reduction (saving)	Metric (ton)		375.024
Total	Metric (ton)		1.973.250
CO2 emission			
Currently	kg CO ₂ e/m ³		1.465.323
Reduction (saving)	kg CO₂e/m³		234.015
Total	kg CO ₂ e/m ³		1.231.308
Concrete Mixer			
Currently	pl		234.827
Reduction (saving)	pl		37.502
Total	pl		197.325

■ Trucks (pl)
 ■ Material metric (ton)
 ■ CO2



This includes three stainless-steel water tanks: a 160 m³ firefighting water tank, a 120 m³ cold-water tank, and a 55 m³ hot-water tank. These are mounted on concrete foundations that transfer the loads vertically into the reinforced concrete frame. Additional chillers for hot-water generation are placed on separate foundations. Alongside connecting pipework, the roof also accommodates exhaust systems for kitchen and bathroom shafts as well as outdoor AC units for technical rooms (Figure 5.6).

As context information, a central cistern is located between the twin towers Tonkin 1 and 2 above the underground car park, storing municipal water. After filtration through sand filters in the basement, the water is pumped to the roof tanks, from where static pressure, supplemented by booster pumps, distributes it throughout the building. Accordingly, pump rooms are located both in the basement and on the roof. The sprinkler system serving the public corridors is also situated on the roof in a separate technical room. Although the available planning documents did not allow for a complete reconstruction of the system, site inspections and discussions with the building management clarified many request for information.

The water supply and corridor cooling are thus not centralised from below but delivered from above - figuratively "from the head of the building." All stainless-steel tanks and technical devices remain fully exposed to solar radiation and weather conditions year-round, with condensation consistently observed on tank surfaces. Roof greening for shading of the upper floors was neither implemented nor retrofittable at the current stage without major structural intervention. Consequently, greening scenarios were only simulated virtually and presented to the developer.

The focus of the analysis lies in the loads introduced by this arrangement of MEP systems - particularly AC units and their brackets - which might be reduced through updated technologies and alternative configurations. The data compiled in Appendix A3.6, derived from planning documents, should be interpreted with caution, yet they provide tangible values: facade-mounted units impose shear forces of approximately 84 tonnes, while rooftop equipment contributes vertical loads of approximately 400 tonnes. Photographic and empirical analysis further revealed differentiated load distributions, depending on the unit owner who is responsible for mounting its own AC unit: the east and west façades carry the highest loads, with approximately 41 tonnes and 36 tonnes respectively, while the south facade carries no AC units. The north facade instead, due to the allocation of loggias, provides space for mounting and calculated loads of around 6 tonnes. For reference, the combined load corresponds to the take-off weight of an Airbus A380 (\approx 560 tonnes) seen in Figure 5.6 (a) and Appendix A2. Relocating rooftop MEP components to the basement would reduce the overall mass distribution of the building that has an effect to the foundation pillars. The aim is to store and supply water directly from the basement, for example via a booster

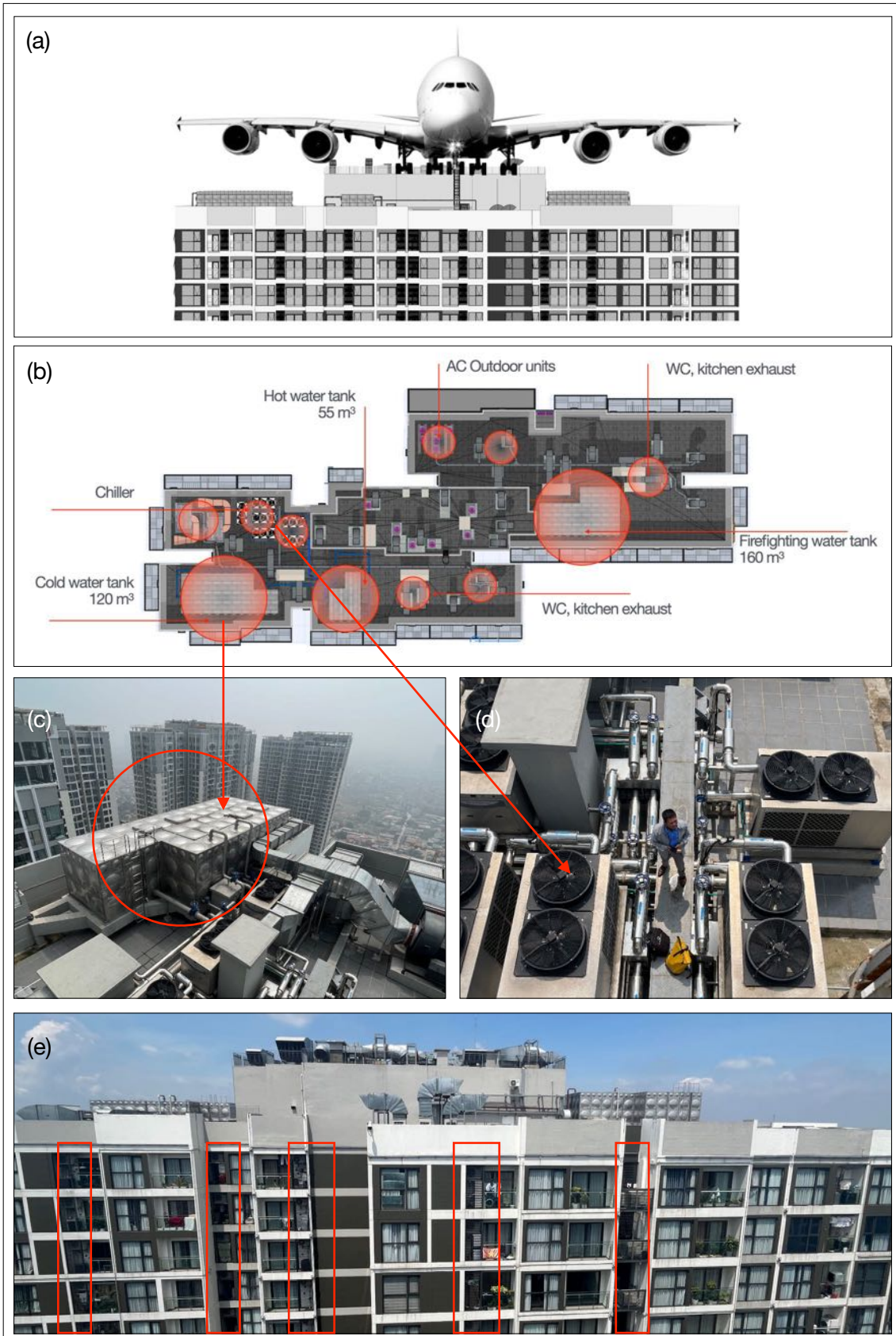


Figure 5.6: (a) Load Comparison A380 on T2, (b) As-built Technical Equipment Arrangement, (c) Cold Water Tank, (e) Chillers, (e) Areas for Wall mounted AC Outdoor Unit/Split

pump system, rather than routing it through to the roof tanks. This relocation would also offer additional advantages by keeping stored water in the shaded and cooler basement environment, decreasing affection of bacteria whilst improving both treatment efficiency and operational resilience.

Usage of Augmented and Virtual Reality:

The use of augmented reality (AR) offers significant advantages for technical coordination, particularly when all project partners employ the same tools from the early beginning of the planning process. It is important to emphasise, however, that within this research project only digital shadows of the case study buildings Tonkin 2 and TestBed 2 were created. These models do not claim completeness but serve as partial representations for analytical and communicative purposes.

The digital models were first developed in CAD software and subsequently exported via add-ons, partly as direct Link. In the case of Tonkin 2 and TestBed 2, a direct export to Twinmotion as virtual engine was possible, while Unreal Engine required conversion via the .datasmith format before further editing. Twinmotion outputs met the visual requirements for communication and decision support on site, but carried the risk of being perceived as gaming environment. Surface information was represented, whereas technical information was not transmitted. By contrast, AR models exported construction, product, and material data and thus enabled visual representation of otherwise non-visible information. For this reason, AR proved particularly useful at early stages for identifying and discussing technical problems requiring solutions. The visual representation was therefore kept deliberately simple to focus on essential, non-visible technical parameters.

The distinction between the two modes of representation became evident in practice: local partners and building owners primarily engaged with the virtual model, while the technical AR model was used mainly by engineering staff. An attempt was made to embed the AR model into the project website via a hot link through the BIMx model transfer platform. This revealed problems related to the differing functionalities of the educational and professional software versions - issues that were only partially resolved by the provider. A particular limitation was the 24-hour restriction of the display mode, which complicated problem-solving across long distances and often led to delays that could not be fully mitigated. By contrast, embedding the virtual model via video placeholders on the project website was straightforward. So basically AR Models were placed as images rather than integrated Links.

From the outset, interface integration was further complicated by the fact that the project website could not be hosted on the university's server but had to be provided by a third-party platform outside academia. For this reason, the digital shadows were ultimately presented via static image formats (AR) or video formats (VR). Real-time

data integration was not possible. Methodologically, this approach proved valid (Figure 4.7), yet it was constrained by persistent issues of feedback latency and interface compatibility or operability. The mixture of third-party providers, cloud platforms, academic institutions, and private-sector partners across two countries was ambitious, but could not be implemented without technical frictions. The virtual model, in contrast to the augmented model, was able to replicate the physical object with high fidelity, including materials and vegetation. A drone survey conducted after the planting of TestBed 2 confirmed this correspondence, underscoring the extent to which virtual environments increasingly approximate real-world conditions.

Reflections

Building Skin and Materials:

The critical investigation of the building envelope and its materiality frames the building as a 'living organism', revealing both systemic strengths and weaknesses that inform strategies for future construction. A comprehensive understanding of the envelope as an integrated whole, and of the parameters that shape its performance, is essential. Yet, in practice, material choices are rarely determined by holistic evaluation. Instead, they are guided by cost calculations and amortisation against time factors, with deficiencies often deferred to the operational sphere of facility management. This results in a narrow optimisation of short-term expenditure rather than a long-term pursuit of resilience and resource efficiency.

Resource-conscious planning requires extended considerations during the early design phase, a process frequently perceived as inefficient within conventional construction practice. However, once translated to the level of construction logistics and workforce effort (one labor calculations), the systemic leverage points become clear. Material mass and embodied energy illustrate this vividly: the difference between an AAC block wall with adhesive joints and a conventional double-brick wall is not marginal but structural, reducing overall wall thickness, mortar consumption, and weight on the foundation. When extrapolated to the scale of a 145 m high-rise or the overall skyline, these savings correspond to dozens of truckloads and significant CO₂ reductions. Although comparisons to the weight of aircraft or freight convoys may appear exaggerated, they are effective in communicating the magnitude of construction material flows and their climate impacts.

The envelope must therefore be viewed not merely as a protective skin but as a decisive parameter in shaping building performance. Window-to-wall ratios (WWR) and building coverage ratios (BCR) influence daylight access, energy consumption, and thermal balance. One possible design strategy would be to reduce window area

by 30 - 50 percent, thereby increasing the proportion of masonry. While such an approach might appear restrictive, it can in fact reduce the amount of internal shading devices such as curtains, while still ensuring adequate daylight levels whilst improved wall performances. Another scenario would be to add a second skin that takes responsibility for shading and therefore cooling. Then in contrast window areas could be wider and curtains might be not necessary.

Mortar and plaster thickness, though seemingly minor, compound into significant material and emission factors at scale. Thermal imaging confirms the effect: poorly insulated joints, under-dimensioned plaster layers, or unshaded glazing generate measurable thermal bridges and surface overheating, accelerating urban heat-island effects. The Tonkin 2 case illustrates how such inefficiencies accumulate across entire ensembles of typologically identical towers, amplifying systemic vulnerabilities within the district.

The reflection that emerges is twofold. First, resource efficiency and climate-conscious construction must be established as design necessities rather than post hoc management tasks. Second, efficiency does not necessarily conflict with cost parity. On the contrary, equal cost alternatives can be identified that reduce embodied mass, improve thermal performance, enhance architectural quality and comfort. Realistic optimisation of costs should follow once these parameters are secured, ensuring that building envelopes evolve into adaptive, low-impact systems rather than persistent liabilities.

Augmented and Virtual Reality:

Across the construction industry, and particularly in the development of large-scale urban districts, implementation techniques are continuously refined to improve efficiency. Smart City projects exemplify this trend, as their execution demands sophisticated organisational and technical coordination. Such requirements are typically addressed through management tools that facilitate communication across multiple stakeholders. In practice, the scale and complexity of these projects restrict delivery to a small number of established firms, usually employing more than 500 staff. Consequently, the market segment is dominated by a limited number of major corporations.

In Vietnam, the high-rise and housing sectors are likewise led by a handful of large companies. In Hanoi, prominent actors include Hoa Binh Construction, Cotecons, Unicons, Newtecons, and Delta. Public tenders in this field are largely circulated within this closed professional network. Within these firms, Building Information Modeling (BIM) has become an established tool for planning and coordination, providing three-dimensional animated construction models that support workflows.

Within the Smart Urban Areas (SUA) project, BIM was also employed to generate

digital models of the investigated buildings. This process was, however, constrained by the availability and quality of technical documentation. For Tonkin 2, the dataset did not reflect the final as-built condition, while documentation for TestBed 02 contained discrepancies that required extensive on-site verification. For TestBeds 01 and 06, technical documentation was entirely absent, necessitating reconstruction of the models from site sketches and empirical knowledge.

The strength of three-dimensional modeling lies in its ability to integrate, verify, and cross-reference structural information. During the reconstruction of the Tonkin Tower ensemble, including its basement levels, the transfer of two-dimensional drawings into the BIM environment revealed errors such as misaligned walls, misplaced service shafts, and inconsistent column grids. Hence the documentation received belongs to Tonkin 1 and was digital mirrored. These discrepancies could not be clarified with the local partner, as communication with the Vinhomes planning team was mediated through corporate communication departments rather than technical staff. At TestBed 02, the absence of direct contact with the design office likewise restricted the verification process, as technical information was transmitted indirectly via the building owner.

Such examples highlight the extent to which collaborative workflows can be compromised by communication barriers. To mitigate these limitations, digital models were generated based on the received documentation, existing site conditions and accumulated field experience in Vietnam. This distinction revealed a critical methodological insight: a difference between Digital Twins (DTs) and Digital Shadows (DSs). A DT is developed from the earliest planning stages, partly managed through BIM contracts, and consolidates multidisciplinary data in interoperable formats (e.g., IFC). It represents a 1:1 digital counterpart of the physical asset, enabling real-time monitoring and predictive adjustments. By contrast, the SUA models must be classified as digital shadows, as linear non interacting models: retrospective, partial reconstructions of the assumed current state, without the data provenance, traceability, or collaborative integration of a true DT. Despite these limitations, the DSs provided a functional basis for simulations and supported the exploration of interface constraints and applied BIM practices in real-world contexts.

Although BIM models are rich in data, they are often too complex for non-specialist audiences. One advantage lies in their capacity to generate environments in Augmented Reality (AR) and Virtual Reality (VR). AR overlays digital information onto the physical building and its immediate surroundings, while VR expands the scope to immersive representations of the urban environment. Within the SUA project, VR models were adapted for head-mounted displays and embedded into the project website, where they served as interactive media for communication. The VR models provided immersive yet simplified reconstructions, occasionally perceived as gamified

environments, whereas AR models were oriented toward technical users, offering targeted overlays of construction, material, and product data.

This experience underscores a broader lesson: while BIM adoption in the construction industry continues to expand, its potential for simulation and predictive design remains underutilised. The incomplete integration of SUA climate sensors into the AR environment highlights these constraints but also points toward a future opportunity. Linking real-time environmental data with digital building models remains a promising pathway for enhancing planning reliability, adaptive management, and resilience in high-rise developments.

The reflections on building envelopes and materiality suggest that buildings must be understood not only as static containers of use but as evolving organisms embedded in wider systems of urbanity. The envelope becomes an interface where material choices, energy performance, and urban climate converge. When multiplied across high-rise ensembles such as Tonkin 2, even modest adjustments - whether reducing glazing ratios, optimising wall compositions, or integrating greenery - scale into significant shifts in urban energy balance and resource demand. This perspective resonates with the visionary systems thinking of the 1960s and 1970s mentioned in Chapter 2, when architects, builders and scientists alike imagined infrastructures as adaptive, self-regulating environments.

5.3 Vegetation Placement and Sensors - Results and Reflections

Results

Vegetation benefits and maintaining:

Within the framework of the SUA research project, the roof and facade greening system was implemented using standardised containers arranged in accordance with the planting concept, enabling later dismantling. To minimise direct contact with the terracotta roof tiles, the containers were elevated by 50-55 mm on conventional bricks, a requirement agreed in coordination with the building owner.

Containers A, B, and C, described in Chapter 4.4, are widely available on the Vietnamese market and posed no challenges. Corresponding, containers A and B are typically used for motorcycle deliveries, while container C is commonly used for packaging and storage. Native plant species were placed in containers A and B to establish a 'rooftop forest' that could be monitored with the installed sensor system. System comparability with TestBed 1 (TB1) was an essential criterion, facilitating analytical comparison of two rooftop gardens in different Hanoi districts. After eight months in operation the first bird nesting was observed (Figure 5.7) at TestBed 2 (TB2).

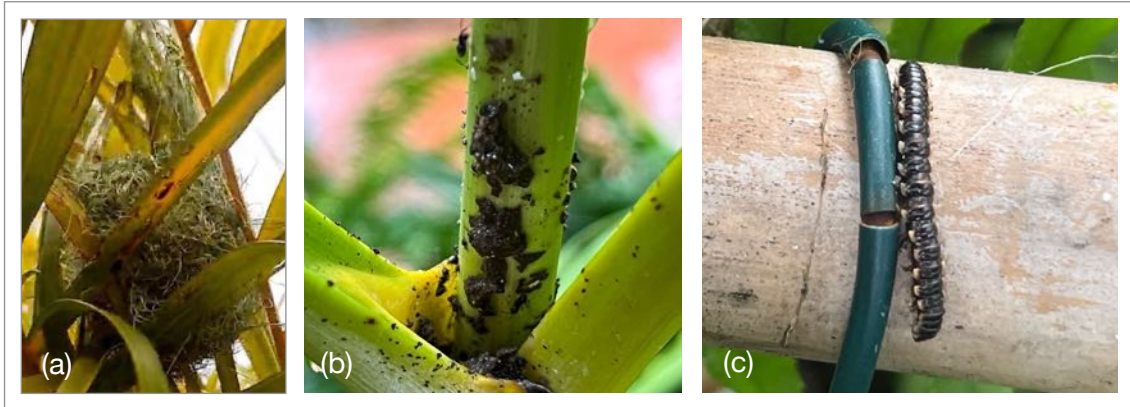


Figure 5.7: (a) Bird Nesting at TB2, (b) Ant Settlement in the Palm Leaf Sheath, (c) Caterpillar on Bamboo Bracing

The roof's elevation of 23 m above street level further proved insect and bird concentrations at this height. Additional planting of blossom vegetation (Bird paradise / *Strelitzia reginae*) after 10 months of the initial installation of TB2 further supports fauna attraction. Nevertheless ants and caterpillars settlements were discovered within one year. Ants in particular were attracted to the palm leaf sheath as protective environment with access to water that runs down the leaf stem collected by the leaf blade.

In addition to the documented increase in local insect biodiversity, thermal imaging observations and measurements (Chapter 5.1) confirmed the advantages of vegetated building envelopes, as illustrated in Tables 5.4-5.6. Maximum temperature peaks of up to 11 °C were recorded between vegetated and non-vegetated facades. Further benefits of green roofs are shown in Table 5.7, where temperature maxima of exposed metal roofs are compared with vegetation shaded surfaces. In conjunction with the reference values in Table 5.2, these findings indicate average surface temperature reductions of approximately 30 °C between non-vegetated and vegetated, shaded surfaces. The reduction of solar load on wall surfaces is therefore largely absorbed by the vegetation layer of the green facade. When combined with optimised wall materials - such as the use of AAC blocks (Chapter 5.2) - these effects enable the design of double-layered exterior walls that expose interior spaces to significantly lower baseline temperatures.

With focus on observations from TB2 a recognisable difference in palm development was observed between both TB1 and TB2. Delivered Palms to TB1 reached 2.5-3.0 m height with robust single stems, while those delivered to TB2 were shorter (1.8-2.5 m) in height and often with multiple shoots at base. Shorter palms showed greater flexibility during the storm-prone annual season (July–September), but subsequently avoided slower canopy growth and increased basal shoot formation. This intensified shading of the shrub and ground-cover layers, limiting their development. Three major

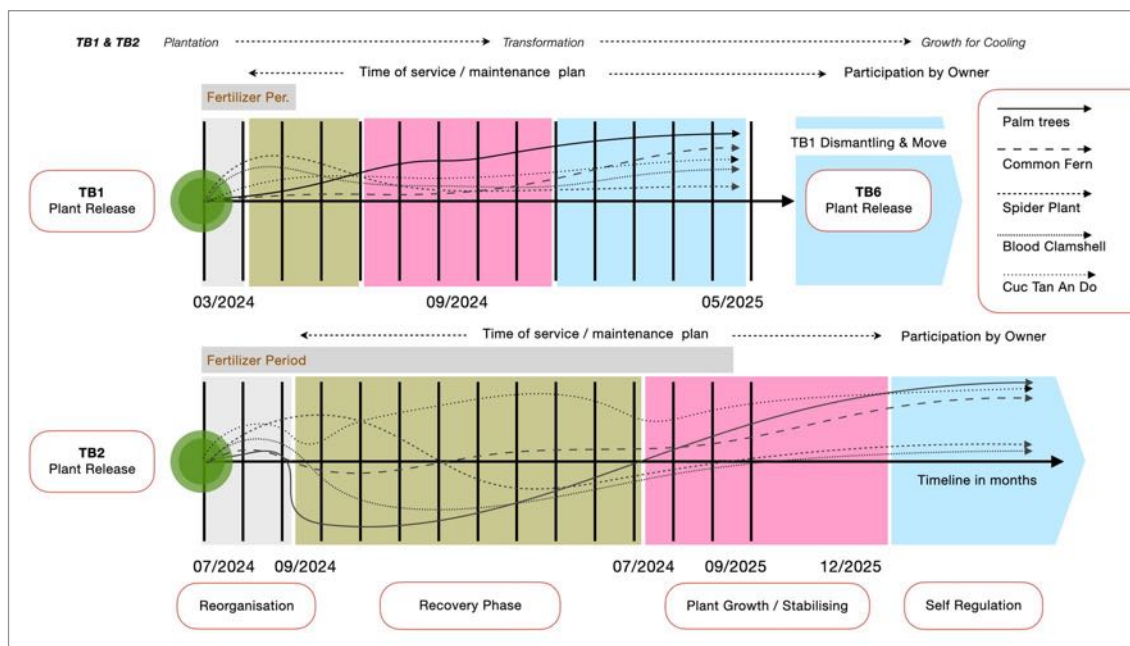


Figure 5.8: Plant Rehabilitation at TB1 and TB2

pruning in the basal area over a year helped to guide growth vertical rather horizontal. To further support root establishment for stability, the Japanese fertiliser HB-101 was recommended by the landscaper. Watering one to three times weekly within the first weeks are necessary, as palms were delivered with pruned root systems. Vigorous root regeneration confirmed the efficacy of this measure. A bamboo bracing frame was additionally installed to stabilise the palms during the first months and support stability during typhoon season. The bracing was maintained three times within the first year. At time of September 2025, the roof garden reached an age of 14 months, the stability of the palms is that quality that the bracing can be removed. 120 kg soil plant was added to the containers A and B after three months again due soil settling.

Weather extremes and plant rehabilitation:

On 7 September 2024, typhoon Yagi struck northern Vietnam, classified as a “century storm” with wind strengths of 6-7 Bft³³. The event caused widespread power outages and uprooted trees across Hanoi. Despite these conditions, the rooftop and facade greening system and the sensor network at TB2 remained operational. The observation camera continued functioning despite heavy vibrations and provided uninterrupted image and video recordings³⁴. Observation unfold that non vegetation was unrooted but the palm blades sustained significant leaf damage at the leaf edges. The impact of typhoon Yagi therefore provided an unexpected while valuable stress

³³ Beaufort Wind Force Scale

³⁴ <https://smarturbanareas.de/sua-dashboard/sua-dashboard-tb2.html> (14.09.2025)

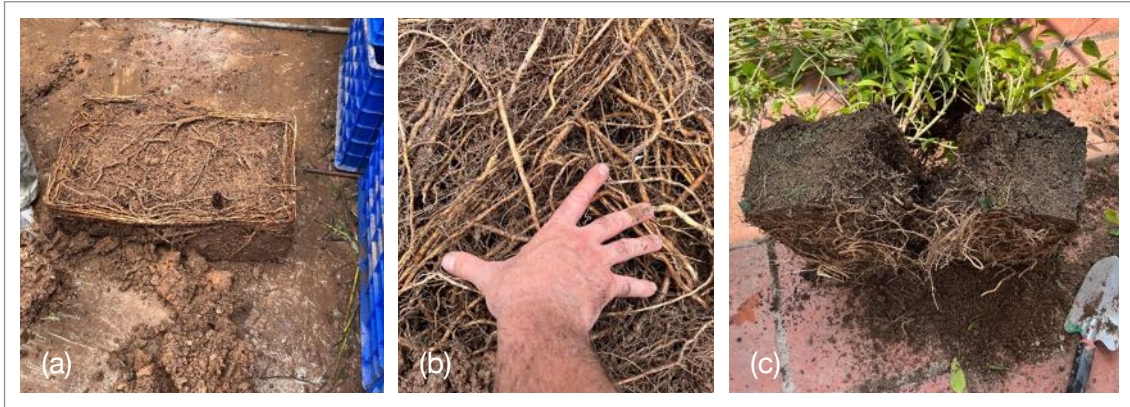


Figure 5.9: (a) Palm Roots from A and B Container TB1, (b) Close up to Palm Roots in Container, (c) Separation hanging Plants and Rooting

test for TB2. During measures of TestBed 1 (TB1) and TestBed 2 (TB2) notable patterns of plant regeneration revealed, although causal attribution to local conditions remains partly uncertain or not evident enough. Figure 5.8 illustrates the vegetation dynamics over a 14-month period. At TB1, the treetop layer - after planting - reached approximately 2 meters above the ground-covering vegetation, consisting primarily of *Nephrolepis exaltata* (common fern), *Chlorophytum comosum* (spider plant), and *Tradescantia spathacea* (blood clamshell). The testbed was located on the fifth floor and surrounded by adjacent buildings and walls on three sides, with exposure only to the west. As a result, natural influences were moderated, with light and air entering primarily from above, while wind and storm impacts such as typhoon Yagi caused less damage compared to open streetscapes or unprotected rooftops. Vegetation dynamics at TB1 followed a distinct succession. During the initial rehabilitation phase, spider plants expanded vigorously and produced numerous offshoots. After eight months, a shift was observed as blood clamshell outcompeted spider plants, while ferns continued to thrive steadily in the shaded centre of the setup. By the end of the 14-month period, shortly before the dismantling and relocation of TB1 becoming TB6, spider plants had nearly disappeared. Ground cover was dominated by blood clamshell and extensively developed fern, while palms had become well-established, anchoring themselves structurally and increasing in height by approximately 80 cm, even extending through the rooftop construction. In contrast, the climbing species *Dyopsis lutescens* (Cuc Tan An Do) showed limited growth throughout the observation period.

At TB2 in contrast, the vegetation development over the same period showed both parallels and divergences. Spider plants initially dominated were progressively displaced by fern and blood clamshell, which asserted dominance in at least three containers. A temporary snail infestation led to losses but was compensated by replanting offshoots sourced from TB1. Palm development proved more influential

than anticipated: dense treetop growth suppressed ground-cover expansion. Only after the radical pruning of palm shoots to 1-3 main stems, did essential support plant recovery. Damage sustained by palm leaves from Typhoon Yagi - occurring two months after planting, a time when plants are in their recovery phase - took approximately 12 months to fully regenerate. In this interval, ferns expanded vigorously, surpassing both spider plants and blood clamshell in height and width, and ultimately gained dominance in containers A and B through its vast expand of shoots. Spider plants and blood clamshell are reduced to a minor but equal position in the container. An additional planting of *Strelitzia reginae* (Bird of paradise) in previously damaged areas successfully established itself and competed successful with the fern, though it is not listed in Figure 5.8 due to its role as a special planting. Cuc Tan An Do as hanging plant showed an immense growth rate of about 3 m over 12 months with a minor set back in recovery after Typhoon Yagi - who set the benchmark. Due its high pace in growth Cuc Tan An Do was cut after twelve months by the owner.

Overall palm growth at TB2 was substantial, with height increases of up to 1 m, confirming that radical shoot pruning successfully channelled energy into vertical growth while improving light and spatial availability for the understory. A side note of this development has been the progressive shading of sensor nodes by palm fronds, suggesting that repositioning or elevation of the solar panels will soon be required to maintain functionality.

Keeping the focus on the palm again comparable patterns were observed in root development. The heavily pruned root balls of palms and climbing plants regenerated with unexpected vigor. At delivery, the palms for TB1 and TB2 were supplied with knotted root balls no larger than 30 cm in diameter for a better handling. The bamboo frames installed against wind loads initially served primarily to stabilise the palms against one another and to prevent toppling. These frames, extending approximately 50 cm above the soil surface, ensured upright growth during the establishment phase. During the dismantling of TB1, plants designated for reuse were separated and stored. Several palms had to be cut out of their containers because the expanded root systems made them too heavy for transport. The root balls had grown so extensively that the new mass exceeded manageable weight limits for labours to carry. At the container base, root mats of 8 - 10 cm thickness had formed, particularly in containers A and B for palms, and in container C for the climbing species. Figure 5.9 illustrates this root expansion, highlighting the structural anchoring capacity of the planting system and the plants' adaptation to confined container environments.

A closer look: The roots proved soft and flexible, intertwining within the confined space of the planting containers in search of optimal anchorage. This natural stabilisation expanded the foundation area of the palms and provided a stronger counterweight against wind loads. After approximately 14 months, the bamboo



Figure 5.10: (a) Ring-Drip Irrigation at TB1, (b) Mist-Drip Irrigation for Container A and B at TB2, (c) Drip Irrigation for Container C at TB2

bracing system was no longer necessary, except as protection against vertical displacement. By this stage, following the recovery period from implementing in July 2024 and storm damage, the palms had developed sufficient anchorage and stability to withstand wind exposure independently.

Irrigation observation:

Irrigation systems at TB1 and TB2 sourced locally available standard components but delivered different results. TB1 used ring-drip hoses with 10 cm outlet spacing, which ensured uniform water distribution. TB2 employed flexible hoses with combined misting and drip outlets at container A and B; at containers C, only drip nozzles were installed (Figure 5.10). This led to uneven watering and dry zones in the beginning, reducing growth in certain areas until adjusting was done. The misting function at containers A and B proved beneficial, cooling palm stems and reducing heat-stress responses, whereas drip irrigation alone was comparatively weak. Heat flux observations confirmed that palm stems reached elevated surface temperatures, regulating stomata activity.

Overall, TB1 irrigation achieved more consistent substrate moisture, while TB2's system produced patchier growth outcomes. The survival of the greening system and the functionality of the sensors demonstrated resilience, though structural stabilisation measures (bamboo bracing, container elevation and tie-back) were essential. Such exceptional events underline the need for adaptive greening systems that can withstand extreme weather conditions and maintain ecological as well as technical functions in the greater urban environment.

Sensor installation, placement and product constraints:

The DAVIS sensor network on the roof of TestBed 2 was installed for microclimatic monitoring of the vegetation and the immediate building environment. Following

detailed planning and technical consultation with the supplier's support team, the system was successfully assembled and put into operation. During the initialisation, however, software-related difficulties occurred when integrating the soil sensors for the planting containers C on the south and west façades. These sensors could not be activated despite the replacement of several drivers. In contrast, the Sentek soil sensor (length 300 mm) installed in one of the rooftop planting containers A consistently delivered reliable data.

The system issued its first warning messages in late November 2024. Data interruptions occurred in connection with construction activities at the south façade carried out by the building owner. Battery warnings followed from December 2024 - approximately six months after installation. The gateway, powered by a solar panel and a 6 V battery, was initially mounted upright on the southern wall of the rooftop structure and provided stable performance. The system's nodes were connected to the gateway via Bluetooth, fixed to the masonry using a steel bar, and oriented east-west. The individual sensors were wired to the nodes with long cables well suited for extended distances. Each node was additionally equipped with four D4 batteries and powered by a solar panel with backup from the integrated battery. The batteries were designed to bridge periods of insufficient solar charging. In most cases, all four sensor slots in the node housing were occupied. By January 2025, battery warnings were being reported from all nodes, and further data outages were recorded.

In mid-April, the gateway-node-sensor network was inspected on site after the majority of sensors had been transmitting data unreliably for several weeks. A complete system failure was confirmed between late March and mid April 2025, around ten months after installation. Communication with the German distributor and support team did not yield any solutions. According to their statements, such a total failure had not previously been encountered. Externally, orange-rust discolouration was visible on the hardware and sensor cables leading out of the nodes, with similar signs at the mounting points (Figure 5.11). On opening the nodes, corroded battery caps and leakages were observed, which had damaged the metallic plate connectors of the battery holders. This accounted for the battery failure messages and ultimately led to the discolouration. It was further noted that the IP44 splash-proof casings of the nodes were indeed tightly sealed and mechanically robust. However, this construction favoured condensation inside the housings, accelerating corrosion of the battery caps and leading to short circuits. The solar panels mounted on the casing lids generated considerable heat, producing strong temperature differences inside the housings - another driver of condensation in the tropical environment. The temperatures must have been substantial, as some battery tops and bottoms were found to have ruptured. Follow-up queries and exchanges with the supplier, and even direct contact with the manufacturer in California, remained inconclusive. At present, only the

meteorological station Vantage Pro2 continues to deliver reliable data.

Closer inspection of the gateway as the central hub of the network revealed that its battery provided insufficient performance. The 6V battery (made in Vietnam) was recharged with a charging station, the gateway was repositioned horizontally on a support bracket, and the solar panel thereby received direct daylight primarily from above and the west. This repositioning demonstrated that both the gateway and the nodes operate more accurate and reliable when installed horizontally. Another probable factor in the node failures was shading of the solar panels caused by the growth of the palm trees from plant containers A and B, which prevented adequate battery charging. Nevertheless, this does not resolve the fundamental issue of condensation inside the casings. In short, a microclimate developed within the sealed casings themselves, directly affecting the electronics.

Moreover, prolonged exposure to high levels of ultraviolet (UV) radiation, in combination with Hanoi's humid climate and elevated air pollution, caused visible material degradation on exposed components - mostly fasteners. In particular, plastic elements exhibited signs of embrittlement and fatigue. As a preventive measure, switching to more durable materials, such as natural fibre cords (Flax), is recommended to enhance long-term environmental resilience. For this study, therefore, only the data collected during the first seven months after installation can be considered reliable. The quality of the measurements besides visibility in the Application dashboard is high, but the operational stability is restricted and requires a more intensive maintenance effort than initially anticipated.

Reflections

General observations and experiences:

The vegetation experiments provide important lessons for rooftop greening initiatives. Increasing plant diversity is recommended to enhance both ecological and health performance. Greater species variation can improve shading, cooling capacity, and resilience, while also promoting the settlement of birds and insects. The nesting observed at TB2 underscores the potential of rooftop gardens to create habitats even in dense urban environments.

Differences in palm development highlight the importance of species and planting selection. Palms with a minimum initial height of 2.5 m are preferable, as they develop stronger canopies and maintain sufficient clearance for understory vegetation. Single-stem palms are recommended because they direct growth energy into height and crown development rather than basal shoot extension, which at TB2 inhibited shrub expansion. In addition, planting should be scheduled to avoid the storm-prone summer months (May to September), when peak solar radiation, high temperatures,

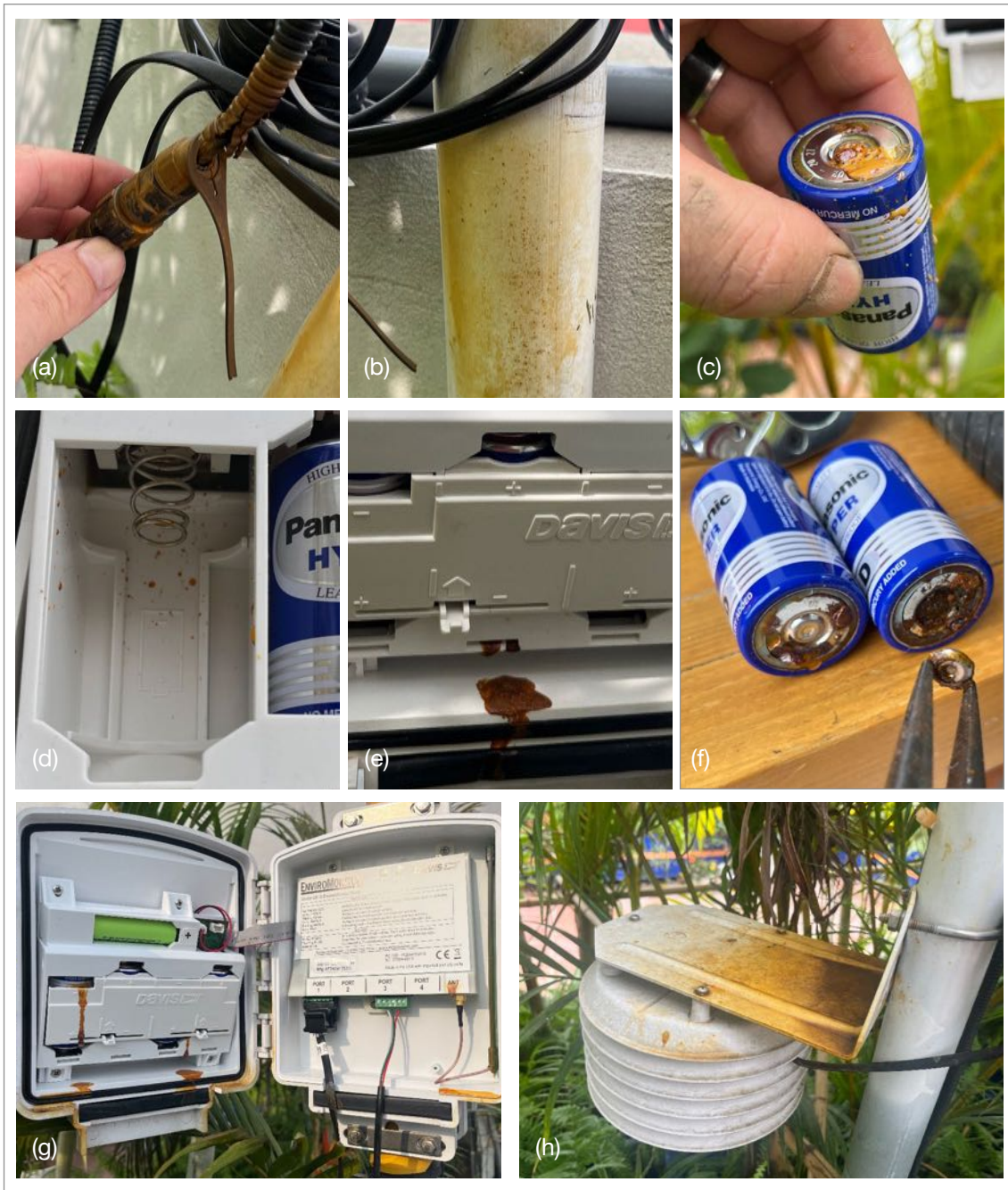


Figure 5.11: Deface in Node Casing and on Equipment after ten Months since Commissioning. (a) Discolouration on Wire, (b) Discolouration on Metal Post, (c) ruptured Battery Bottom, (d) in Battery Holder, (e) in Case, (f) ruptured Battery Heads, (g) Deface in Case, (h) Discolouration on Equipment (rel. Humidity / amb. Temperature Sensor)

and heavy rainfall coincide. Establishment during February-April or October-December reduces stress factors and promotes more stable vegetation growth.

The Irrigation design proved critical. Uniform distribution at TB1 delivered consistent development, while patchy distribution at TB2 initially limited plant performance. A practical modification for container type C is relocating drainage holes from the base

to the side walls, approximately 3 cm above the container bottom, to retain soil moisture and reduce excessive drainage. This adjustment enhances water availability during dry seasons and improves flexibility in irrigation control. With regard to climbing species, planting a single *Cuc Tan An Do* per container is advisable, as its vigorous root growth tends to outcompete neighbouring plants. Although efficient for facade greening, this species is a “soil consumer” and requires periodic soil replenishment. Seasonal irrigation adjustment is also essential: during the rainy summer months irrigation may be reduced or temporarily shut down, but such measures must be coordinated with the water filtration system as part of the integrated filtrate cycle. For this purpose, more advanced technical equipment and external monitoring are recommended, rather than relying solely on manual commissioning by building owners.

Neighbourhood dynamics play an important role in construction processes in Vietnam. In a city such as Hanoi, where building activity is constant, neighbours cannot be assumed to be uniform stakeholders. In the case of TB2, despite prior notification, installations on the critical west-facing wall ultimately had to be dismantled - fortunately only after the data collection phase was completed. Since buildings in Hanoi are typically constructed up to the property boundary, any overhanging element requires explicit neighbour approval. For TB2, negotiations involved 13 different neighbours, which illustrates how even well-conceived technical approaches encounter limitations in practice. Against this backdrop, the successful implementation of the rooftop greening system can be regarded as a noteworthy achievement.

Overall, the findings confirm that rooftop vegetation functions more than a decorative element. It simultaneously provides habitat, cooling, and resilience benefits for the building envelope. However, its success depends on deliberate system design: careful species selection, well-engineered irrigation, and structural reinforcement. These insights reinforce the value of rooftop greening as an adaptive strategy for high-density urban contexts such as Hanoi and other cities located within the equatorial belt.

Miyawaki roof vegetation:

The original method of applying three biological substrate layers was adopted and adapted to the local context using available products. This approach served as a proof of concept in the implemented test fields, demonstrating that both substrate stratification and the combination of diverse plant species accelerated growth within a short period. The resulting vegetation provided clear benefits in terms of shading the building envelope and supporting local fauna. It also demonstrably reduced rooftop and facade heat absorption and buffered soil moisture, confirming its role as a passive

cooling and retention measure.

In general, Miyawaki-type vegetation on buildings has shown notable resilience factors: high survival rates of planted species, rapid canopy closure, improved soil stabilisation, and a strong capacity for self-regeneration after extreme weather events. These qualities contribute not only to microclimatic regulation but also to long-term ecological stability in dense urban settings.

Although the test fields remain engineer-designed systems, they are expected to “naturalise” over time through continued ecological processes. For future urban planning, it is essential to integrate such insights so that buildings operate as adaptive nodes within wider urban systems. Establishing standardised frameworks for scalable greening strategies can significantly enhance environmental performance and well-being in new developments, and more broadly within the evolving mega-city context.

An observation phenomena, a noteworthy - not validated yet - discovery:

Over the period of 15 months a phenomena was observed regularly, warrants of closer examination, as it illustrates in remarkable clarity how biological organisms in coexistence complement one another within a mutually beneficial system. Beyond its botanical specificity, this example may be understood as a guiding metaphor for the present study and for the SUA project in Vietnam more broadly. Figure 5.12 pictures the relationship between the palm and an ant colony that exemplifies the biological principle of symbiosis, defined as a close relationship between different types of organisms in which they live together and benefit from each other. In this case, the interdependence between the palm (Arecaceae) and the ants offers a vivid demonstration of a natural system loop, characterised by reciprocal advantages and sustained by minimal external inputs. The palm produces new height by forming fronds composed of three parts: the leaf base (sheath), petiole, and the fan-shaped or pinnate blade. In the case of the butterfly palm, rainfall collected on the leaf blade is channelled towards the concave petiole and subsequently guided into the lower leaf base, which enfolds the trunk as the plant grows until the frond is shed. At the transition between petiole and leaf sheath, a lip-shaped thickening rises slightly above the concave channel, allowing water to run in a controlled manner along the trunk. This “lip” functions as a funnel-like interface between the leaf and the stem. Through the narrow gap between the sheath and the trunk, a film of moisture reaches the growing stem (Fig. 5.12 (a)), cooling the meristem during periods of high temperature. The palm thus acquires water not only through its root system but also through this highly effective leaf-based collection mechanism. This internally coherent cycle alone is notable, as it reveals an autonomous cooling strategy extending across the entire height of the plant - far exceeding the limited reach of artificial misting systems applied at the base of TestBed 2.

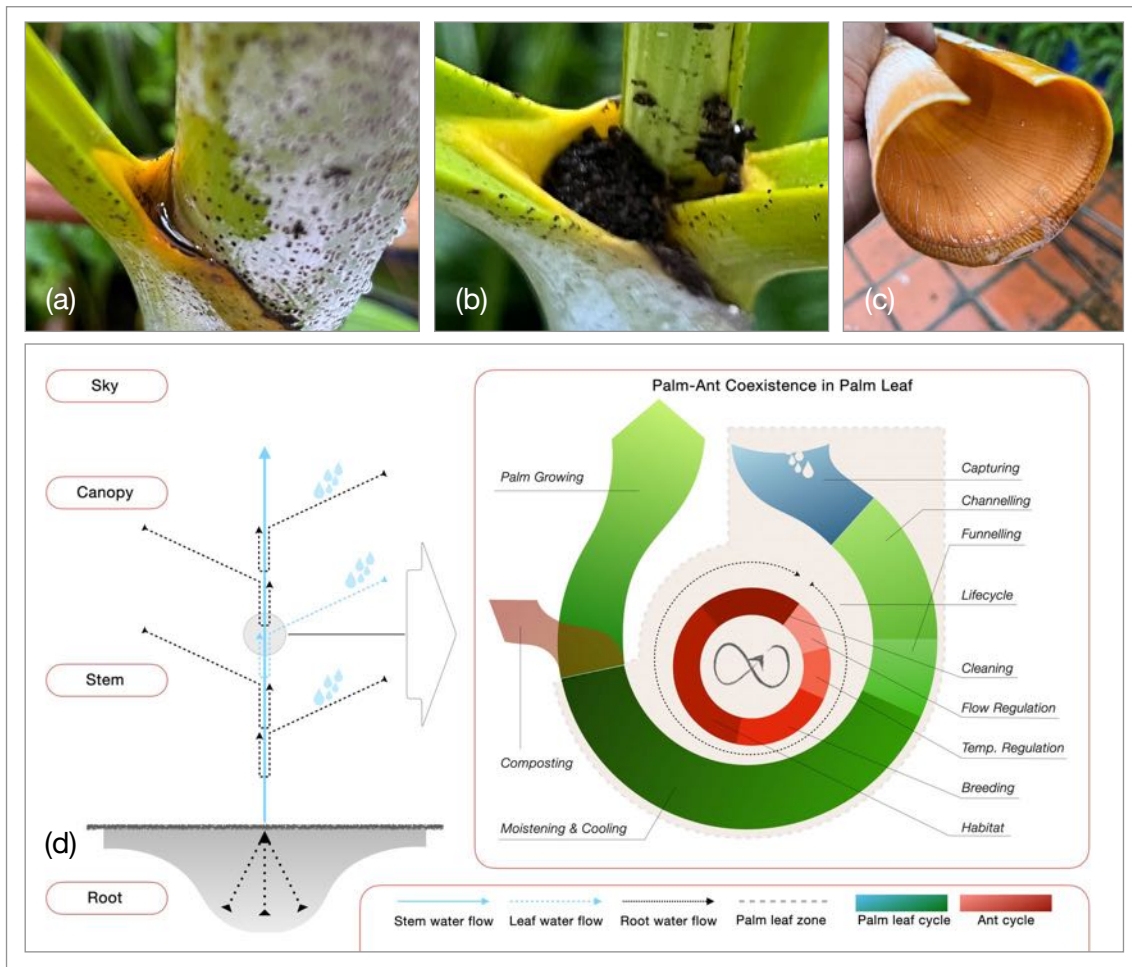


Figure 5.12: (a) Lip filled with Water, (b) Lip filled with Soil, (c) Sheath after Removal, (d) Coexistence System

How to understand a symbiosis as feedback loop within? The symbiotic dimension becomes visible in the lower half of the palm, precisely in the zone around the “lip.” Repeated observations showed ant colonies establishing themselves in the narrow funnel-like space between the leaf sheath and the trunk. When fresh sheaths were removed, entire colonies with egg clusters were found in this micro-habitat. The water film (Fig. 5.12 (c)) that cools the palm simultaneously provides a stable, humid, nutrient-rich environment for the ants, facilitating reproduction. Soil particles deposited by the ants (Fig. 5.12 (b)) gradually narrow the opening of the “funnel,” indirectly regulating the inflow of water if the leaf’s channel is oversized - an inadvertent yet beneficial modulation of the palm’s cooling function.

As the frond ages, it undergoes a multi-week process of detachment: it discolours, dries, hardens, and eventually separates from the trunk by itself. The ants detect this condition change early and relocate to a younger, moisture-providing sheath. The palm thus serves as a host organism, offering shelter, humidity, and structural stability; in return, the ants maintain the stem by removing small organisms and organic debris.

This closed, temporally evolving loop represents a transient yet efficient symbiotic system - an autonomous, self-sustaining habitat governed by adaptive feedback and iteration. The figure 5.12 illustrates the biological reciprocal system as a diagram, highlighting its conceptual relevance as a model for adaptive, self-sustaining urban nodes.

Operational recommendation for green roofs:

The management of the two green spaces on Buildings TB1 (till May 2025) and TB2 has been intensively monitored, allowing for the establishment of a maintenance plan after fourteen months. Following the initial establishment phase - which spans two to three weeks depending on the roof area - a maintenance period for care, fertilisation, and after-treatment commences. Once the vegetation has stabilised in its species composition and orientation, typically after twelve to eighteen months, the gardens can be formally transferred to the participating owner for self-management. Due to the self-regulating nature of these gardens and/or engineered forests, the vegetation naturally develops through the exogenous addition of seeds via local fauna. This natural progression is only interrupted or significantly altered when human intervention occurs and the species composition is fundamentally changed. Such an alteration necessitates the start of a new rehabilitation and recovery cycle.

Sensor network:

The sensor network was commissioned under normal conditions but required adjustments at an early stage. Additional facade works may have caused temporary disturbances to the installation. Ideally, all nodes should be mounted horizontally and oriented to the west; however, this proved difficult to achieve within the constraints of the dense urban building configuration. The most serious technical issue was battery corrosion, which caused persistent damage and has not yet been fully resolved.

Despite these challenges, the quality of the collected data remained within scientific standards and was readily usable in mobile applications and research. Communication with the manufacturer in the United States and the distributor in Germany proved lengthy. Nevertheless, the distributor responded positively by supplying replacement parts to repair the corroded contact plates, while no feedback has yet been received from the manufacturer. Overall, the experience underscores the necessity of adapting hardware specifications to local environmental conditions in order to ensure long-term system reliability. A further critical point concerns the supply chain of the 6V battery. Although manufactured in Vietnam, the unit was procured through a German distributor, resulting in a logistical loop in which the battery was shipped from Vietnam to Germany and subsequently back to Vietnam. This process leaves an ecological footprint that warrants critical reflection. While this issue extends beyond the SUA

project to the global battery market as a whole, it illustrates the systemic contradictions that can undermine otherwise sustainability-oriented initiatives.

Cost calculations:

The calculated results for building greening derived from the Master's thesis by Sophie Girlich from TU Berlin indicate that cost neutrality cannot be achieved when assessed over the full life cycle of 50 years. At present, no financial incentives for green buildings are available in Vietnam, and the integration of sustainability measures therefore depends largely on the voluntary initiative of individual investors. According to Girlich, cost reductions can only be realised through regulatory adjustments and increased frequency of application. As awareness grows regarding use, management, and the associated social added value, demand is expected to rise, fostering competition among providers and ultimately leading to lower costs. A contributor to sustainable developments anchored the LOTUS certification strategies of the Vietnam Green Building Council (VGBC) as advisor of the Vietnam Ministry of Construction.

Apart this context, so-called "soft factors" must be strategically and sustainably established as value-generating elements. Comfort-related qualities that enhance well-being contribute directly to improved living conditions and, in turn, to increased property value, thereby making such investments more attractive to investors. It should be noted, however, that Girlich's analysis did not incorporate the value of filtered water - i.e. recycled wastewater reused for irrigation at TestBed 2 - into the cost and life-cycle calculations. Based on the author's own calculations, which indicate potential water savings of up to 90%, further cost reductions can be expected after accounting for the investment and amortisation of the filtration system and associated piping infrastructure, as significantly less municipal water would need to be purchased from the outset. This assumption, however, requires validation through long-term operation of an optimised filtration system within a real-world project setting. By contrast, the ecological contribution of soft factors to improved quality of life for residents and urbanity can already be confirmed.

5.4 Water Infrastructure - Results and Reflections

Results

Water filtration unit:

The pilot unit WA-MBR-TB225, described in detail in Chapter 4.3, consists of seven modules combining German-manufactured products with locally sourced components, underlining its experimental - prototype character. During commissioning

and early operation, several technical and biological limitations became apparent. The system was initially operated without inoculation using activated sludge (Bun Thai), which is normally recommended to establish aerobic and anoxic bacterial cultures for biological treatment. Attempts to substitute this step through dosing with sugar and Effective Microorganisms (EM) achieved only temporary improvements, with bacterial growth collapsing within days. A second attempt led to the same outcome. Consequently, the system relied primarily on the membranes for water purification. Operational observations indicated additional challenges. In order to avoid premature membrane fouling, the system was operated predominantly with blackwater (80 - 90%) and a minimal proportion of greywater (~5%). This ratio had to be manually adjusted at the ball valves, since no automated valves or sensors were integrated into the unit. Monitoring showed inflows were highest during morning (06:00 - 08:00) and evening (19:00–21:00) hours, consistent with household usage patterns, while greywater flows remained highly volatile and influenced by rainfall events. Heavy rain from May - September (monsoon season) revealed that the 1000 L IBC Mixtank was undersized, requiring frequent additional buffer capacities of up to 3000-5000 liters to manage stormwater inputs, which were not available due the space conditions on site. The building's function as serviced apartments also created a much higher load than typical residential use. Frequent laundry by staff and guests resulted in continuous operation of five washing machines (in average 10 hours per day), with an average of 50 liters consumed per cycle. This substantially increased inflow volumes of grey water distribute system stress in accordance with bacterial growth.

For the commissioning of the system in connection with the riser for rooftop irrigation, the available Wilo Medana high-efficiency pump proved insufficient. Originally intended for TB1, where it was not deployed, it faced higher operational demands in TB2. To address this, a centrifugal pump (Wilo PH-401E) was additionally installed upstream of the Medana pump, thereby increasing both pressure and flow rate. The filtrate tank is improved via a DN 60 PVC/PPR pipeline to the centrifugal pump, which transfers the fluid through a DN 35 PPR pipeline to the Medana pump. Through this additional pressure and flow support, combined with software adjustments in the Medana control, the filtrate reliably reaches the rooftop and supplies the irrigation nozzles with adequate pressure and water volume. Both pumps operate in synchronised mode.

Operational constraints:

After monitoring the daily inflows from the building's four discharge lines - two for greywater (including rainwater) and two for blackwater - their arrangement, with pipes recessed from the basement ceiling, is illustrated in Figure 5.12. The Testbed 2 building is oriented on a north-south axis. Greywater and blackwater pipes 1 are

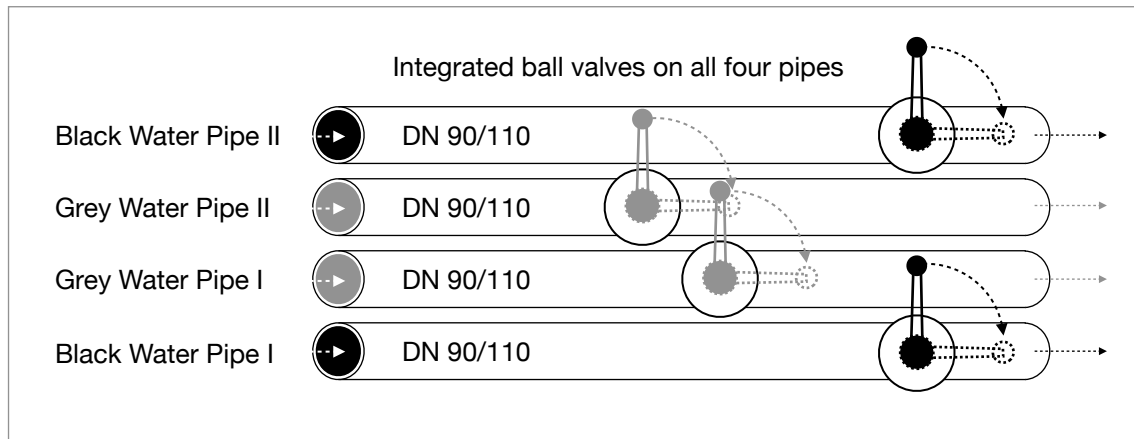



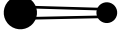

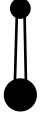











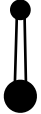
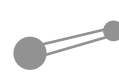

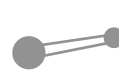
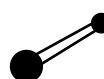

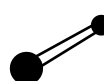
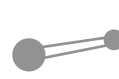













Figure 5.12: Waste Water Pipe Arrangement in the Basement of TestBed 2 with its related Ball Valves.

connected on the east side of the building and include the downpipes from the washing machines, whereas pipes II are connected to the west side. Consequently, greywater pipe I distributes the entire wastewater load from the washing machines. According to the manufacturer and mentioned beforehand, the WA-MBR-TB225 is capable of filtering 5-7 cubic meters of water per day. For this capacity to be achieved, sufficient buffer volume must be available in the form of mix tanks. In the case of TestBed 2, such buffer capacity was not feasible due to spatial constraints. Due to this limited space on-site, the system was constructed in a highly compact form. The initially targeted capacities of 6000 liters (six IBC tanks), three for each of the Mixtank and filtrate tank could not be realised, resulting in a controlled but reduced wastewater inflow. This design leaves no buffer capacity for contingencies such as heavy rainfall or the additional feeding for bacteria growth. The matrix detailing the different ball valve settings and their observed effects incrementally is presented in Table 5.14. To accommodate the inflow volumes, the system was therefore adjusted at the inlet in order to minimise overflow. Therefore repeated manual adjustment of the ball valves were necessary. The results led to the determination that the building produces approximately 90% greywater and 10% blackwater. While a higher proportion of blackwater is necessary for the survival of bacterial cultures, the current inflow only occasionally fills the Mixtank. Although greywater admixture is also required, the optimal ratio remains uncertain. If the greywater share is set too high, the Mixtank is susceptible to overflow, leaving the DN 40 spillway insufficient and avoid bacterias growth. The fluctuations in the two greywater lines, which also carry stormwater, must be balanced to ensure operation. The comparative analysis of the different valve settings demonstrates that stable operation of the WA-MBR-TB225 requires a sufficiently high proportion of blackwater in the intake to sustain bacterial activity. Greywater admixture remains necessary, yet

Table 5.14: Ball Valve Settings and Results

Setting	Pipe No.	Grey Ball Valve	Black Ball Valve	Comment
1	I	0 % 	0 % 	All valves closed; wastewater is discharged to the public sewer.
	II	0 % 	0 % 	
2	I	100 % 	100 % 	All valves opened; wastewater is collected in the Mixtank; overflow anticipated.
	II	100 % 	100 % 	
3	I	50 % 	50 % 	All valves 50% opened; 50% mix of wastewater collected in the Mixtank; blackwater insufficient to sustain bacterial growth; overflow anticipated due to greywater intake.
	II	50 % 	50 % 	
4	I	50 % 	50 % 	Three valves 50% opened; one valve closed: mix of wastewater collected in the Mixtank; blackwater insufficient to sustain bacterial growth; overflow still anticipated due to greywater intake.
	II	0 % 	50 % 	
5	I	15 % 	100 % 	Two greywater valves 15% open; two blackwater valves 100% open; blackwater sufficient to sustain bacterial growth; overflow risk present; greywater admixture favourable due to less washing machine residue.
	II	15 % 	100 % 	
6	I	10 % 	30 % 	One greywater valve closed; one greywater valve 10% open; two blackwater valves 30% open; Mixtank keep on level of 350L; not sufficient or alarm.
	II	0 % 	30 % 	
7	I	10 % 	50 % 	Two greywater valves 10% opened; two black water

Setting	Pipe No.	Grey Ball Valve	Black Ball Valve	Comment
7	II	10 % 	50 % 	valves 50% opened; heavy rainfall causes overflow alarm.
8	I	5 % 	95 % 	Two greywater valves 5% open; two blackwater valves 95% open; system stabilises rainwater impact and meets blackwater demand.
	II	5 % 	95 % 	
9	I	3 % 	97 % 	Two greywater valves 3% open; two blackwater valves 97% open; bacterial growth maintained; no overflow risk; greywater nearly closed, still supplemented by rainwater.
	II	3 % 	97 % 	

its proportion is difficult to regulate due to variable inflows and rainfall events. During Typhoon Yagi, which passed over Hanoi between 6 and 9 October 2024, the weather station at TB2 recorded a maximum precipitation rate of 217.4 mm/hr. By contrast, no reliable measurements could be taken during Typhoon Bualoi (28 September-3 October 2025), as the weather station, camera, and sensor network malfunctioned due to roof flooding. Such volumes of stormwater significantly increase the risk of Mixtank overflow, while insufficient blackwater content diminishes biological performance.

The findings highlight that manual valve regulation can stabilise the system temporarily, but long-term reliability requires larger buffer volumes and automated control to balance the competing demands of bacterial growth, stormwater management, and operational safety. Since 19 May 2025, the system has been operated for irrigation purposes using the valve configuration defined in Scenario 9. Under these settings, stable operation was maintained throughout summer 2025 until mid-August, when Mixtank overflow alarms and overheating warnings were triggered, particularly for the Medana pump. Remote monitoring via the installed on-site camera, which provided live display access, together with coordination with the local technician, enabled partial restoration of control without altering valve settings, as such adjustments are time-consuming. Subsequent alerts, including error code 420 from the Medana pump, led to the decision to shut down the irrigation function while maintaining limited filtration until further evaluation.

Further instances of external interference with the wastewater treatment cycle were reported by the building owner. These included the deactivation of the filtrate pump at the filter unit and, more critically, the unauthorised opening of the rooftop water tank inlet valve, which caused filtrate to enter the domestic water supply. In this case, residents reported odour and quality concerns.

Water consumption evaluations:

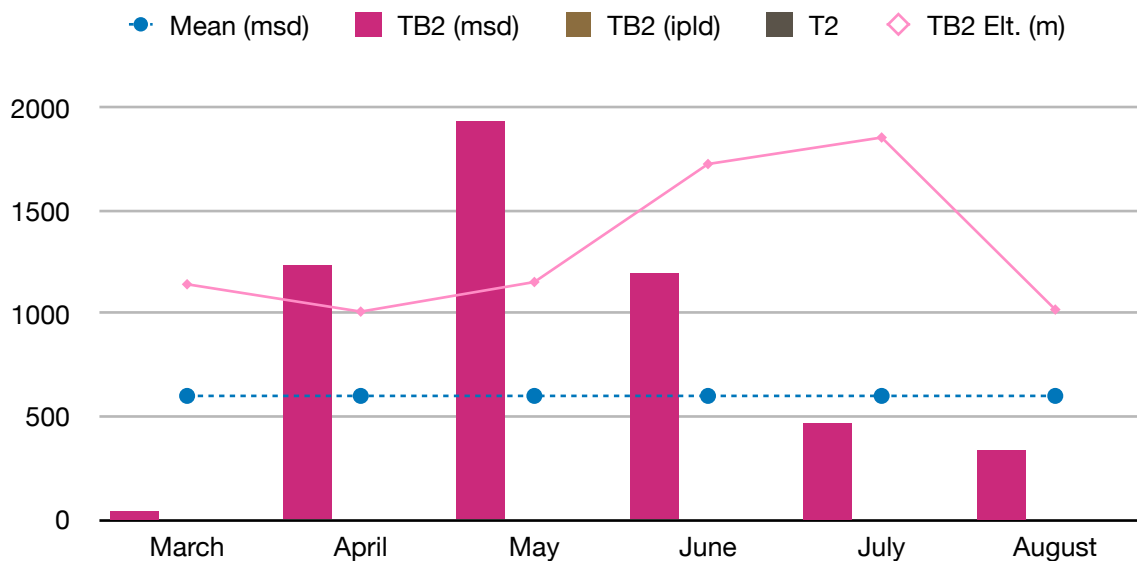
Based on the observations from Setting 9 and the information knowledge gains summarised in Appendix A.6 and in Table 5.15 can be derived. For the calculation of overall water demand, an average consumption of 130 liters per capita per day was applied. At full occupancy of TestBed 2, with a maximum of 50 residents, this corresponds to a total municipal water consumption of 6,500 liters per day (6.5 m³). The consumption assumptions and calculations are based on publicly available pricing information, as the actual water and electricity bills (operational costs) for both TestBed 2 and Tonkin 2 were not disclosed.

The figures are interpolated on the assumption that Setting 9 physically taps and filters a portion of the wastewater. In this configuration, the ratio of 95/5 blackwater to greywater is maintained, as presented in Table 5.15. If 100% of the wastewater were to be treated, the ratio would reverse to 10/90 (blackwater to greywater), with an estimated 3% loss attributed to bacterial processes and solid components redirected into the sewage system. Under current conditions, the trend line indicates 598 litres (0.60 m³) of filtered water for TestBed 2 since the “System Go” date of 19 May 2025, demonstrating that the filtration unit is currently operating at approximately one-fifth to one-tenth of its rated capacity on intake water. A confusing aspect is the 50% of pipe usage - 100 % black water equals two water pipes, while just 3% of greywater is led into the Mixtank - the two grey water pipes operating nearly closed. The greywater pipes deliver five to ten times more water. Based on this knowledge, the corresponding data for Tonkin 2 has been interpolated.

Rainfall events are generally difficult to calculate in advance due to the high fluctuations. At present, all three irrigation lines (1, 2, and 3) on the roof and facade are scheduled to three minutes at 06:00 morning and 20:00 in the evening, consuming 132 liters of filtrated water each cycle and 264 liters of filtrate per day. Under the current configuration of Setting 9, the filtrate output covers two days of irrigation demand. This balance will change once washing machines are also supplied with filtrate water. The calculations in table 5.15 are based on full occupancy. Based on this table, potential savings from wastewater treatment were calculated for the high-rise buildings of the Smart City. With 90% filtration of greywater, approximately 419,515,200 liters per month can be reused, while 10% filtration of blackwater corresponds to 46,613,800 liters per month. Scaled to one year and multiplied by the

Table 5.15: Water Consumption and Cost (Benefits)

Bldg	Residents (r)		Intake Water (L/r)		Filtered Water (L)			
	(min)	(max)	(Day)	(Month)	(Day)		(Month)	
					(Grey)	(Black)	(Grey)	(Black)
Ratio	Measured (msd)				5	95	5	95
TB 2	25		3.250	97.500	163	3.088	4.875	92.625
		50	6.500	195.000	325	6.175	9.750	185.250
Ratio	Interpolated (ipld)				90	10	90	10
TB 2	25		3.250	97.500	2.925	325	87.750	9.750
		50	6.500	195.000	5.850	650	175.500	19.500
Ratio	Interpolated (ipld)				90	10	90	10
T2	1.560		202.800	6.084.000				
		1.992	258.960	7.768.800				
VSC	60 towers, Tonkin type, liters/month		365.040.000		328.536.000		36.504.000	
			466.128.000		419.515.200		46.612.800	
VSC	Per year in cubic meter		1,15 USD*/m ³		US\$ 4.533.796,80	US\$ 503.755,20		
			1,15 USD*/m ³		US\$ 5.789.309,76	US\$ 643.256,64		



* 30.09.2025: 1 cubic meter water, 30.000 VND, 1,15 USD (Oanda)

current unit price of water, this equates to an estimated saving of around 6 million USD in water costs. Beyond financial savings, the primary value lies in the sustainable reuse of water that would otherwise need to be procured from municipal supply. These potential savings should be compared against the investment costs of installing a wastewater treatment unit for each tower in order to calculate amortisation. In Vietnam, amortisation periods are typically set at 12 months, a benchmark that should be considered in stakeholder communication.

Energy consumption:

Based on the measurements recorded at TB2 (Appendix A6) for the period from March to September 2025, and up to the deactivation of the wastewater treatment plant (WWTP) at the end of September, an average energy consumption of 1,318.5 kWh per month was observed following the official “System Go” on 19 May 2025. This energy demand relates to the filtration unit, which during this period filtered approximately 120 m³ of water, albeit with reductions in output efficiency. As the system operated in prototype mode and faced persistent technical compromises from the outset, these values cannot yet be considered reliable for precise calculation or as a definitive basis for dimensioning but functions as proof of concept to establish a water cycle and loop within buildings.

Additional consideration:

One parameter largely absent from the literature is the inflow of bottled or otherwise self-supplied drinking water into buildings. As municipal supply water is not potable, drinking water is transported into the building in containers of 19 L, 5 L, 2 L, or 1 L. A proportion of residents also use mobile kitchen filter systems that generate potable water from the municipal supply, although no reliable data exist for this practice. Although Elliott, Foster, and MacDonald (2021) report³⁵ that in urban areas of Pacific Asia, especially Vietnam, 18% of urban residents rely on self-supplied water sources, field observations in TestBed 2 suggest that the actual proportion may be significantly higher, potentially approaching 50% in the high-rise contexts of Tonkin 2. An indicative estimate, such as 3 L per capita per day, would be misleading in the absence of validated information but should be examined in greater depth in future calculations. Such inflows could substantially alter assessments of building-scale resilience. Each kilogram of externally introduced weight also affects the overall system, whether through additional structural loads or through the potential need for infrastructural optimisation, such as the integration of decentralised potable water treatment units.

³⁵ <https://www.nature.com/articles/s41545-021-00121-6> (25.08.2025)



Figure 5.12: Filtrate Examples for Water Quality Certificates, 16.06.2025. (a) both Samples in 2 Liter Canisters, (b) Sample of Filtrate, (c) Sample of Tap Water

Water Filtrate Analysis:

To verify the quality of the filtrate and compare it against national water quality regulations, two laboratory tests were conducted. On 19 May 2025, two litres of water were sampled from the filtrate tank of the WA-MBR-TB225 filtration unit and submitted for analysis at the Institute of Chemistry, Vietnam Academy of Science and Technology (full certificates see Appendix B3.3). A second sampling took place on 16 June 2025 (Figure 5.13), comprising both filtrate and municipal supply water, in order to reconfirm the extreme values observed in the first test. The comparative analysis of city water from the rooftop tap (lobby water) and two successive filtrate samples from the WA-MBR-TB225 shows significant deviations (Table 5.16) regarding the national quality regulation (QCVN 01-1:2018/BYT). While the municipal supply largely met the requirements - apart from the detection of *Pseudomonas aeruginosa* (6.3×10^1 CFU/100 mL) - both filtrate samples exhibited critical exceedances.

Most evident are the elevated concentrations of nitrogen compounds. Ammonium levels reached 8.15 mg/L in May and 7.21 mg/L in June, exceeding the allowable limit (0.3 mg/L) by more than an order of magnitude. Nitrate (39.5 mg/L in May; 31.6 mg/L in June) and nitrite (1.59 mg/L and 0.34 mg/L, respectively) also remained well above permissible thresholds. These findings point to incomplete biological treatment within the MBR system. Organic loading, expressed through the permanganate index, was likewise elevated in both filtrate measurements (6.4 and 6.2 mg/L compared with a limit of 2.0 mg/L). Microbiological parameters varied between the two filtrate samples. In May, total coliform (3 CFU/100 mL) and *E. coli* (6 CFU/100 mL) exceeded national standards, while *Pseudomonas aeruginosa* was not detected. In June, *E. coli* was no longer present, and coliforms were reduced to the detection threshold; however, *Pseudomonas aeruginosa* was measured at 1.1×10^2 CFU/100 mL - considerably above the regulatory limit and higher than in the municipal reference water. Overall,

Table 5.16: Water Quality Differences of Tap Water, Filtrate and Regulation

Parameters	Unit	Tab Water 17.06.2025	Filtrate (WA-MBR- TB225) 19.05.2025	Filtrate (WA-MBR- TB225) 17.06.2025	QCVN 01-1:2018/ BYT
Colour	TCU	<1	40	36	15
pH	-	8	7,34	6,55	6,0-8,5
Hardness	mg/L	100	112,0	180,0	300
TDS*	mg/L	119,7	317,0	977,0	1.000
NH ₄ ⁺ - Ammonium	mg/L	0,02	8,145	7,211	0,3
Cl - Chloride	mg/L	8,51	44,67	127,62	250
NO ₃ ⁻ - Nitrate	mg/L	1,373	39,481	31,642	2
NO ₂ ⁻ - Nitrate	mg/L	0,014	1,588	0,340	0,05
Na - Sodium	mg/L	0,154	0,2056	0,006	200
SO ₄ - Sulfate	mg/L	8,18	26,6	77,82	250
Permanganate Index	mg/L	0,1	6,4	6,2	2,0
Total Coliform	CFU/100mL	0	3	1	<1
Escherichia coli (E.coli)	CFU/100mL	0	6	0	<3
Pseudomonas aeruginosa	CFU/100mL	6,3x10 ¹	0	1,1x10 ²	<1
*	Total Dissolved Solids				

the data suggest that although the MBR system achieved partial reduction of microbial indicators between May and June, the persistence of nitrogen compounds and opportunistic bacteria prevents compliance with domestic water standards. The results demonstrate that, under current operation, the filtrate does not provide the expected improvement over municipal water and requires further optimisation.

Reflections

Water filter unit:

First of all, this The heterogeneous material composition of the pilot unit illustrates its prototype status and offers insight for future adaptations. For cost-efficient manufacturing in Vietnam, the substitution of IBC containers with polypropylene (PP)

tanks is recommended, as this would facilitate the integration of fittings and reduce leakage risks at plastic–metal transitions. Likewise, the stainless-steel nitrification filter used in the prototype could be replaced by PP tanks, offering local manufacturing, simplified logistics, and weight reduction especially for building integration later on. Two alternative design concepts can be derived:

- A. Integration of all treatment stages, pumps, and fittings into a single PP module.
- B. Division of the system into three to four PP modules, allowing greater flexibility, easier transport, and simplified revisioning.

Hence, future systems should prioritise prefabricated PP modules to minimise the number of critical interfaces, shorten installation times, and thereby reduce overall costs. Preconfigured control units and the use of 8 - 10 mm rubber mats would further enhance reliability by mitigating noise, leakage, and seal wear. Project experience also emphasised the importance of inoculating biological stages with activated sludge from the beginning. Without this step, bacterial growth remained minimal and purification performance insufficient. Beyond these technical considerations, contextual conditions such as seasonal rainfall, volatile greywater inflows, and cultural practices strongly influenced system behaviour. Summer storms highlighted the need for larger buffer tanks, while high daily shower frequencies and intensive laundry use significantly increased inflow and organic load compared to European contexts.

In operational practice, the system faced challenges typical of pilot products. During the first seven months, frequent adjustments and continuous monitoring were necessary to stabilise performance. Critical failures exposed further weaknesses: support from the German manufacturer was difficult to obtain, particularly during summer vacation periods (June to August), when the system itself was under peak demand. In such cases, the filtration unit had to be taken offline, with wastewater temporarily redirected to the conventional sewer infrastructure until maintenance could be completed. Another challenge concerns the lack of vocational training or curricula for local technicians while the system remains in its test phase. Without this capacity-building, potential customers remain hesitant to adopt new technologies. This became evident in mid-August 2025, when the Medana irrigation pump issued error code 420, indicating the need for hardware and/or software replacement, a damage that could not be resolved locally.

Despite these constraints, the WA-MBR-TB225 pilot has demonstrated proof of concept. Since May 2025, rooftop greening has been irrigated with filtrate, demonstrating that treated wastewater can effectively substitute for municipal supply. Subject to confirmation of water quality, filtrate use could also be extended to washing machines, thereby amplifying water reuse and improving the efficiency of available

resources. Taken together, these findings represent tangible contributions to urban resilience, complementing the thermal and cooling benefits of the building envelope.

Water Quality Improvements:

Based on the values presented in Table 5.16, it is pertinent to consider which measures are required to ensure that the filtrate reaches the quality of municipal tap water, or at minimum complies with the national water quality regulation (QCVN 01-1:2018/BYT). To improve filtrate quality and extend its usability beyond irrigation, targeted optimisation measures are necessary. The persistently elevated concentrations of ammonium, nitrate, and nitrite (NH_4^+ , NO_3^- , NO_2^-) indicate that the biological treatment stages should be reinforced, for example through extended aeration regimes or by adding a post-denitrification step with carbon dosing. Where such process adaptations are not feasible, downstream upgrading options such as ion exchange or zeolite filtration could provide a practical retrofit, depending on on-site conditions. Microbiological exceedances further underline the need for a final disinfection stage. Ultraviolet (UV) irradiation offers a compact and chemical-free solution, while low-dose chlorination could be considered for systems with storage capacity. However, chlorination entails higher maintenance requirements, undermines sustainability considerations, and disqualifies the filtrate for irrigation use. To further reduce residual organic content and improve colour, an activated carbon filter downstream of the MBR is recommended. A combined polishing sequence of MBR treatment, UV disinfection, and activated carbon would significantly enhance filtrate quality, enabling reliable application for laundry purposes while reinforcing the contribution of decentralised systems to urban water resilience.

Considering the observed water balance in TestBed 2, with 95% greywater and 5% blackwater measured, it would also be feasible to operate the filtration system exclusively on greywater, given that the blackwater share is limited primarily to support bacterial cultures. Such an approach could reduce the overall system scale and circumvent the difficulties associated with bacterial inoculation. In turn, investment and maintenance costs could be lowered, thereby reducing barriers to the adoption of decentralised treatment systems in high-rise buildings.

Water Cycles and circularity:

The concept of circular resource management within buildings remains largely novel and must first be explained and established at a fundamental level. Practices such as rainwater harvesting or wastewater filtration have so far not been systematically integrated into buildings - particularly high-rises - yet they offer significant potential as ancillary costs for water supply continue to rise, as already observed in many Western countries. Despite high levels of annual rainfall, Vietnam faces declining groundwater

levels, which will increasingly compel urban areas to seek decentralised solutions in the near future. The implementation of water filtration systems may still be three to five years ahead of market readiness, as investment willingness remains limited. Nevertheless, it is essential to foster a shift in thinking toward decentralised water provision, whereby treated water is reused for toilet flushing and irrigation. This requires the installation of piping systems from technical spaces to toilets and irrigation outlets - design elements that are not yet standard in building codes or planning guidelines.

Particularly during the storm season, large reserves of rainwater could be stored to mitigate flooding, as illustrated by Typhoon Bualoi in late September and early October 2025 with precipitation rise up to 400 mm per hour. This approach can be seen as an extension of the “sponge city” concept: green roofs serve as storage surfaces, while technical floors house cisterns for rainwater retention or treated greywater. In this way, the urban water cycle could be closed, reducing the burden on municipal sewer systems by regulating stormwater discharge. Tokyo provides a reference, having developed large underground cisterns for stormwater retention over several decades - costly constructions reminiscent of Roman cisterns in Constantinople (Istanbul) and Rome millenniums ago.

From today’s perspective, and especially with regard to rapidly growing megacities in the equatorial belt between 30° north and south latitude - where flat roofs are set the standard - extensive green roof surfaces could be understood as retention basins rather than sponge-like installations at street level. In this shift, rooftop surfaces, whether privately or publicly accessible, would function as cooling interfaces for the urban organism while simultaneously improving indoor comfort at the building scale. The greatest obstacles to such measures remain questions of conviction and economic competition. In equatorial regions, air-conditioning systems represent the primary monetary competitor. Yet this balance may change rapidly once heat stress and urban heat islands reach levels of social and environmental intolerance. Intensive green roofs should therefore be understood not as a burden, but as a protective and comfort-enhancing infrastructure.

5.5 Participation

Experience from the project implementation:

During the project period - particularly in the second half, when implementation gained momentum - valuable insights into participation and collaboration were obtained. The local private partner Vinhomes expressed concerns regarding facade and roof greening at Tonkin 2 due to operational constraints. As a result, these measures were not physically realised but instead simulated through a digital shadow model of the

building. Feedback from the partner gradually increased after the completion of TestBed 1 and TestBed 2, as well as the development of digital scenarios for the Smart City and smaller pilot buildings. Eventually, the project team was advised to shift focus toward greening a parking deck. The designated site was later changed from Parkdeck Zone 3 to Parkdeck Zone 4. Both decks represent large sealed surfaces within Vinhomes Smart City Hanoi. Their dark grey tiled roof areas are exposed to high solar radiation and only partially occupied by technical equipment for commercial ground-floor uses. In both cases, retail areas extend across the entry level and parts of the upper floors. These conditions highlighted the potential to transform unused areas into rooftop forests or shaded parks, offering both building-level cooling and community-level green space. The local partner adopted parts of this idea by installing facade greening with automated irrigation on Parkdeck Zone 4. The chosen species, *Vernonia elliptica* (Cuc Tan An Do), combines rapid growth with low maintenance, providing effective shading in a short period. Roof greening, however, was not implemented.

The process for TestBed 1 differed markedly. Implemented with a public partner, Vietnam National University, the project faced irregularities in contractor selection that diverged from German procurement protocols but were resolved internally. The original plan to retrofit a 1980s French-colonial building with facade and roof greening would have required removal of the corrugated metal roof. Following administrative delays, the site was relocated to a privately owned tube house affiliated with the university. This substitution proved advantageous, as it enabled rapid installation within 10 working days, with five additional days of preparation in advance. The Miyawaki-adapted greening method was, for the first time, successfully transferred to a building context in Vietnam. TestBed 1 operated for 18 months, confirming proof of concept before structural deficiencies and planned renovations required its dismantling. Much of the system was quickly repurposed for TestBed 6 in Long Bien. There, collaboration between the private owner, the landscape contractor (who had by then evolved into a service partner since TestBed 2), and the project team demonstrated effective knowledge transfer and joint commitment to advancing environmental technologies.

The identification of TestBed 2 illustrates the importance of personal initiative and local communication for adaptive measures. The rooftop site was secured through direct exchange with the owner, who supported the project from the outset. Early meetings were complemented by sketches, notes, and site visits to TestBed 1, which helped to build trust and overcome acceptance barriers. With the owner's support, detailed planning was completed by mid-2024 based on as-built drawings, integrated into ArchiCAD 27, and developed as a digital shadow in 3D. Outputs in AR (BIMx) and VR (TwinMotion) facilitated transnational communication between Germany and Vietnam,

accelerating design revisions and strengthening mutual understanding. Construction of the green roof, including irrigation, required four weeks: five working days for installation and the remainder for preparation and adjustments. The WA-MBR-TB225 water filtration system was subsequently added, demonstrating circular economy principles at the building scale. Both systems - the vegetation modules and the water filter - represent novel applications in Vietnam and remain prototypes, yet they illustrate adaptive reconfiguration alongside technological advancement.

The owner's active participation was decisive. He engaged with planning details, optimised the garden design, assumed responsibility for negotiations with neighbouring households in the dense urban fabric, and co-financed selected improvements (e.g. leaf screens). Given Hanoi's narrow alleyways and building-to-boundary typology, early communication with neighbours proved essential to secure implementation - conditions that can shift unexpectedly at short notice. TestBed 2 was therefore a rare case in which ownership engagement extended beyond formal approval to sustained commitment: the owner assumed responsibility for maintenance after installation and continues to manage the rooftop greenery personally and in accordance with his own needs.

Reflections on Collaboration:

Collaboration across Germany and Vietnam required constant exchange, conducted primarily via the local platform Zalo. Lessons drawn from these experiences indicate that cooperation with small to medium-sized enterprises (SMEs) offers the greatest potential for innovation and timely implementation. SMEs demonstrated interest not only in socio-ecological ambitions but also in the economic opportunities of environmental technologies, often reinvesting benefits into community and ecological value. By contrast, institutional partnerships were frequently characterised by bureaucracy, which slowed progress and reduced effectiveness, often requiring workarounds. Large corporate partners, while resource-rich, exhibited rigid structures and limited flexibility for experimental technologies.

The SUA project thus revealed these contrasts in full. While institutional frameworks introduced delays and constraints, collaboration with SMEs and individual owners enabled adaptive, questioning while rapid, and concrete implementation.

Participation emerged as a decisive factor: private and SME actors provided agility and innovation, whereas corporate and institutional partners often introduced rigidity. This spectrum of experiences generated valuable insights into the conditions under which participation can meaningfully contribute to urban innovation and development.

Final note on technical equipment in the tropical environment:

Across all technical installations - whether LoRaWAN, DAVIS sensors, or the

wastewater treatment unit - first signs of malfunction or instability appeared after six to eight months of operation in general. The LoRaWAN system exhibited data gaps; the DAVIS sensors generated repeated error messages from the seventh month and reached total failure by the tenth month, largely due to battery corrosion that interrupted integral operation. The waste water filtration unit initially performed well, with adjustments required in the second month. However, bacterial cultures could not be stabilised, and by the sixth month the smart pump began overheating while messaging failures. In the seventh month, the system was taken offline in the absence of on-site service capacity, spare parts, or viable local solutions. Overall between six to eight months the technical equipment evolved failures. Such equipment refers to a constant maintenance service.

By contrast, roof and facade vegetation proved to be the most reliable element of the investigations, offering the greatest impact and clear potential for further development.

6 Findings, Vision and Outlook

The theoretical concepts and strategies related to resilience mechanisms in urban development, introduced at the beginning of this dissertation, were methodologically elaborated and examined through quantitative and qualitative case analyses in the preceding chapters. Building on these foundations, Chapter 6.1 consolidates the empirical findings and analytical insights presented in the previous chapters. This section synthesises the behaviour of building envelopes, vegetation systems, decentralised water treatment, digital monitoring infrastructures, and cross-site observations, highlighting how these subsystems interact to produce adaptive performance in high-rise environments.

This chapter provides a summary of the key findings and delivers consolidated answers to the initial research question. Furthermore, it projects the insights from Chapter 5 - aligned with the theoretical frameworks of Chapter 1 into a forward-looking vision, and concludes by outlining limitations and strategies for further development.

6.1 Summary the Objectives

Recap the initial research question, this work and the investigations besides empirical insights developed in the previous chapters demonstrate that high-rise buildings can be understood not as isolated solitary architectural and technical objects but as active subsystems embedded within the larger Metropole areas and urban fabric to mitigate heat stress and increase therefore resilience while contributing to the comfort of living. Drawing on interactions between building envelope performance, vegetative greening systems, decentralised water treatment, digital monitoring infrastructures, and microclimatic surface processes reveal that these elements do not function independently. Instead, they form intertwined and often invisible feedback loops whose combined behaviour determines the adaptive capacity of the building as a whole. The findings from chapter 5 converge into a multidimensional picture, an holistically approach, of how such adaptive performance emerges when material, ecological, and technical components interact dynamically under the extreme conditions characteristic of tropical and sub-tropical megacities as in the example of Hanoi.

The synthesis in this chapter is therefore intended as a conceptual framework - an invitation to question conventional planning paradigms and to sketch pathways toward building models that are more resilient, long-lasting, and contextually grounded. Rapid urban densification in the global South, particularly in Vietnam, demands solutions that exceed the limitations of rigid regulations and slowly evolving standards. With the technologies, scientific knowledge, and engineering expertise

already available today, significantly more adaptive and ecologically integrated high-rise typologies as urban elements are not only imaginable but realistically achievable. Yet the pace of regulatory adaptation lags behind environmental change, constraining innovation at the moment when it is most urgently needed. Given the accelerating dynamics of urban transformation, it is essential to tailor design strategies to local conditions and to engage relevant actors in continuous dialogue. The “Blue Marble” is too fragile for innovation to stagnate in procedural debates or regulatory inertia. The question is about alternative urban models and how they can be systematically articulated and implemented. This chapter therefore positions the high-rise building as a potential Adaptive Node within an interconnected urban metabolism - an approach that aligns architectural design with ecological principles, resource loops, and distributed resilience.

6.1.1 Key Findings of Building Envelope

On the building level, the nano scale, the thermal behaviour of contemporary high-rise facades in Hanoi is determined primarily by their material logic. Brick-concrete walls with cement render exhibit U-values of up to 13 W/m²K (chapter 4.3.5), effectively functioning as thermal radiators rather than protective barriers. Thermographic surveys conducted evidence on multiple buildings across the city of Hanoi, mostly in the western Cau Giay district and Yen Hoa area, revealed persistent afternoon surface temperatures above 55 °C on west-facing facades around 16:00 - the time period of maximum heat load (Table 5.1). These extreme external gains lead to substantial heat storage within the masonry, delaying nocturnal cooling and extending the use of air-conditioning systems. These conditions were confirmed both by the wall-mounted sensor arrays in TestBed 02 as well as through photogrammetric facade measurements taken at Tonkin 2.

Vegetated facade segments demonstrated a pronounced mitigation effect. In absolute terms, the temperature reduction between metallic and ceramic surfaces reached approximately 30%, with an additional reduction of nearly 50% between ceramic and vegetated or shuttered surfaces (i.e. simplified 90°C to 60°C to 30°C). Measurements taken across seasonal campaigns showed that planted sections were up to 11 °C (Table 5.2) cooler than adjacent non-vegetated surfaces on peak days. Strongest cooling effects on the west facade corresponded to periods of direct solar exposure, while the south-facing facade exhibited delayed peak cooling due to its distinct shading pattern. The offset depth of the vegetation structure - 250 mm on the west facade versus 800 mm on the south - proved to be a decisive performance parameter, highlighting the significance of spatial constraints in densely built urban neighbourhoods.

These findings demonstrate that microclimatic regulation arises from the dynamic interplay between material surfaces, vegetation layers, air gaps, and exposure conditions, rather than from any single architectural feature in isolation. Equally importance underlines the findings that protected, cooled, and shaded building envelopes leverage the overall building performance in megacities.

On micro scale, the urban area or district, the material-related findings presented in Chapter 5 provide a broader basis for evaluating how construction practices can support regulatory compliance, environmental performance, and resource-efficiency objectives in rapidly growing urban areas. Thermal bridges are still not understood as essential for the internal operation for buildings. Therefore the comparative analysis between traditional brick masonry and autoclaved aerated concrete (AAC) demonstrated that a shift in using AAC rather than brick could reduce CO₂ emissions by up to 46% and lower truck payloads by approximately 16%. These values are significant when viewed through the operational chain of construction, logistics, and site organisation. At the scale of an entire urban area development, the time-efficiency potential is equally notable, with AAC enabling construction processes that are more than 80% faster than conventional brickwork (Table 5.11).

In addition to these logistical and environmental advantages, lightweight envelope systems such as AAC also provide thermal benefits that help maintain cooler indoor conditions than conventional brick structures. Table 2.2 summarises recent “smart” urban areas in Hanoi - many of which promote IoT- and ICT-driven technologies while still relying on conventional construction methods. This contrast highlights a structural gap between technologically oriented “smart” visions and the material practices that continue to represent current urban development. Applying the material strategies discussed in Chapter 5.2 across the high-rise sectors of these developments would:

- shorten construction timelines by months,
- reduce transport emissions by thousands,
- reduce cement demands by 25%, and
- lower overall CO₂ impacts by 50% or more per project.

Beyond environmental benefits, such shifts contributes to higher living standards, improved thermal comfort, less energy consumption and more sustainable socio-economic development within dense urban areas. The estimated cascading effects from top to bottom of the building and within the multidimensional boundaries may provide economical benefits that currently are underrated - yet not validated.

Besides that Hanoi and comparable megacities face significant pollution challenges resulting from traffic congestion, construction dust, abrasive particulates from urban

surfaces and automotive, industrial emissions, limited natural ventilation, and, at times, the burning of agricultural residues. Implementing the construction and material improvements outlined above would help mitigate these health burdens, strengthening urban resilience and improving overall livability.

An attempt to extrapolate these optimisation effects across all new urban and smart urban areas currently scheduled or under construction in Vietnam lack methodological reliability, given the absence of consolidated and publicly verifiable spatial datasets.

6.1.2 Key Findings of Vegetation System

The greening systems implemented in TestBed 01 and especially 02, based on the Miyawaki inspired planting method, demonstrated a high degree of resilience and self-regulation (chapter 5.3). Species diversity, layered substrate composition, and micro-topographical variation across the A and B planters generated remarkable resistance to both heatwaves and intense downpour events including major typhoons Yagi early September 2024 and Bualoi late September 2025.

Measurements and physical experience confirmed that vegetation functions as a distributed cooling mechanism, operating through self-shading, evapotranspiration, and shading of adjacent surfaces in a mutually reinforcing manner. Following a recovery period of three weeks to two months - depending on location and exposure conditions of TB1 and TB2 - a stabilisation and growth phase of approximately 12 to 18 months ensued (Figure 5.8). After this period, the vegetation operated as an almost autonomous system requiring only minimal maintenance interventions at building level. By that stage, the root systems had developed sufficiently to eliminate the need for the initial bamboo bracing structures (wind loads). Typhoon-related leaf damage recovered naturally. Notably, vegetation delivered the most reliable long-term performance of all systems examined: it continued to grow, regulate moisture, buffer heat, and support micro-ecological processes even as several technological monitoring components experienced failures (chapter 5.3.2).

These observations position vegetation not as ornamental greenery but as a form of living environmental infrastructure capable of contributing to the ecological and operational metabolism of high-rise buildings. Functioning as a 'second skin', it provides both thermal and economic advantages, reinforcing the potential of ecological systems to complement each other (Figure 5.12) and enhance conventional building performance. The above mentioned outcomes underline the perspective of understanding buildings as supporting ecological organisms and, at the metropolitan meso-scale, high-rises as adaptive nodes within wider urban systems. Spinning this thought horizontally from one flat roof to another and vertically connected between different altitudes of building roofs an urban strengthening grid of green infrastructure

can be imagined stretching through the urban fabric. At least from public buildings to another such vegetated spots can be achieved by law and will.

6.1.3 Key Findings of Cycles and Loads

The performance of decentralised water treatment and its interaction with the building structure emerged as a critical component in understanding adaptive behaviour at the nano scale. The WA-MBR-TB225 prototype installation at TestBed 02 demonstrated both the potential and the fragility of decentralised water cycles in high-rise environments under real operating conditions. Although the filtration system was fully functional during commissioning and a proof of concept, challenges in cultivating stable bacterial cultures led to repeated collapses of the biological treatment process, even after attempts to stabilise it using Effective Microorganisms (EM) and sugar supplements. As a result, the membrane modules were required the majority of the purification load, considerably increasing maintenance demands and operational risks. Several technical and spatial constraints became evident during operation. The system required manual balancing of greywater and blackwater inflows, lacked automated valves and sensors, and was highly sensitive to extreme environmental conditions such as heavy rainfall.

These issues were exacerbated by the limited rooftop footprint available for the installation. Under such conditions, the pre-treatment buffer (mixing tank) would need to be substantially enlarged to maintain operational stability. This requirement was further underscored during Typhoon Bualoi, when rainfall measurements in the basement indicated an inflow of 150 liters within 1 minute and 20 seconds, despite the presence of vegetation on the 100 m² rooftop. Extrapolating these values indicates that an eight-floor building would require an untreated-water buffer of approximately 5,000 liters to sustain similar rainfall conditions. In the case of Tonkin 2, with a 1,100 m² rooftop surface, the required buffer volume would increase to around 50,000 liters to enable controlled filtration and subsequent irrigation to vertical or horizontal vegetation. At a district scale, such as the Hanoi Smart City development with 50 high-rise buildings, the estimated rainwater harvesting potential amounts to approximately 2.5 million liters (2,500 m³) per rainfall event. This volume could provide a stable irrigation source for parks and green infrastructure, thereby reducing pressure on municipal systems and demonstrating the broader systemic value of integrating decentralised water management at the building scale, or centralised at the urban-district scale, to support vegetation and microclimate strategies. These considerations align with findings from Sophie Girlich's master thesis that also mentioning declining groundwater levels in Hanoi, reinforcing the potential of rainwater harvesting as a back up. The strategic use of rainwater would therefore not only reduce pressure on local

developers but also strengthen the resilience of urban ecosystems under intensifying climatic and urbanisation pressures.

Further observations of the water cycle provided additional insight into system performance. After six to eight months of operation, the smart pump, one of the most critical components, failed, resulting in downtimes and interruptions in rooftop water supply. External interference and potential tampering were also detected; although their contribution to the malfunction could not be evidently determined. Despite these challenges, the WA-MBR-TB225 prototype demonstrated that decentralised water treatment can provide a reliable source of treated water for irrigation and reuse, if the system is specifically tailored to the building, optimised for local conditions, and adapted to the organic load characteristics of the wastewater. A key finding from the filtration experiments was the unexpected amount of greywater that used as the dominant input for decentralised treatment. The proportion of organic solids, originating mainly from blackwater and essential for sustaining bacterial cultures, can therefore be excluded without compromising treatment potential. The investigations showed that nearly 90% of the required irrigation water could be obtained solely from greywater filtration in TestBed 02, making blackwater treatment unnecessary at this scale. For a Tonkin 2-type building with approximately 1,800 residents, the proportion of blackwater would naturally be higher; however, if the system were designed to process greywater only, the filtration unit could be reorganised and downsized accordingly. This would result in a lighter, more compact system with reduced structural and operational requirements. These discoveries reinforce the potential of decentralised filtration systems to partially close hydrological loops at building level. They also highlight the broader opportunities for integrating water management, vegetation systems, and microclimatic regulation in high-rise districts. To obtain more precise and scalable values for such scenarios, a full-scale investigation on a Tonkin Tower or comparable high-rise typology would be necessary.

A broader questioning of the water cycle also requires considerations about structural weight distribution presented in Chapter 5. These findings directly affect not only the functioning of the decentralised water system but also the building's overall morphology, load paths, and construction logic. At present, more than 500 tonnes of weight are distributed across the rooftop, facade through the concrete framework of the Tonkin high-rise typologies. Reducing the number of rooftop air-conditioning units through the integration of vertical vegetation is the goal. Replacing such loads through lighter, more efficient vegetation, would significantly reduce these force impacts. While such loads suffer to be eliminated entirely, they can be redistributed and utilised more efficiently.

A first step would be relocating the three rooftop reservoirs to the basement or to

intermediate technical floors. Currently, the structural point loads of these tanks require substantial reinforced foundations, increasing the overall concrete volume and embedded carbon of the building. Wind loads further complicate this configuration by introducing additional stresses on both the facade and the elevated tanks. Contemporary pressure-boosting technologies, however, can distribute water precisely and reliably over vertical distances of up to 300 meters, making rooftop storage tanks technically redundant. These adjustments significantly reduce maintenance requirements while improving accessibility and durability, and minimise weather-related material degradation.

The green roof system in TestBed 02 demonstrated that vegetated surfaces can halve rooftop loads if using specific substrate and vegetation (Chapter 5.2.1). For a Tonkin 2-type of building, this effect translates into a more balanced load distribution across the entire roof area.

Collectively, these results position water cycles and structural loads as interdependent systems whose coordinated arrangement is essential for improving environmental performance and urban resilience in high-rises that later may play a crucial role as resource distributive buildings.

6.1.4 Key Findings of Digital Interfaces

Digital monitoring systems formed an essential analytical layer of this research but simultaneously revealed substantial limitations in long-term functionality under tropical conditions. The distributed Davis sensor network - installed across facades, substrates, air cavities, and roof zones - provided high-resolution microclimatic data that enabled the calibration and validation of simulation models (e.g., ENVI-met). However, the system exhibited recurring failures after six to ten months of operation. Corroded batteries, signal interruptions, data gaps, and hardware degradation were observed across all device types integrated into the SUA project.

Many constraints stemmed from the physical, climatic conditions of high humidity, heavy rainfall, intense solar loads, and air pollution that accelerated degradation. Building-management restrictions, partly difficult rooftop access, and neighbourhood negotiations delayed sensor placement and limited opportunities for recalibration. In several cases, inconsistent data patterns - whether not validated data leak or transmission issues - underscoring the fragility of digital infrastructures once deployed beyond controlled laboratory conditions. Despite these limitations, the dataset enabled the detection of microclimatic pattern analysis during operational periods, including facade heat load dynamics, vegetation-induced cooling effects (shading), and substrate responses. These insights demonstrate that digital shadows can function as effective analytical, communication and complementary tools, only when

they are embedded in robust maintenance structures. The task and investment of time into using digital shadows in operational environments of real scenarios should be critically questioned due to their impact in reality. Particular caution is required with current IoT- and ICT-driven trends in the global construction and green development industry, which are often overstated in relation to their operational reliability. The question “what is necessary, feasible or avoidable to increase living in dense urban scenarios or high rises to promote comfort rather than control?” These observations underpin that digital systems must complement, rather than replace, ecological and material infrastructures. They also require substantial maintenance effort and, crucially, a team with both physical and theoretical expertise capable of operating.

The intended integration of the Digital Shadow with real-time microclimatic data could not be fully realised due to a series of technical, organisational, and regulatory constraints. These limitations resulted from incomplete, outdated or inaccessible building information, equipment failures that generated data gaps or prolonged system downtimes, or privacy regulations affecting collaboration between academia and the private sector. Additional challenges arose from cloud-based software interfaces, data overload, data cleaning, and the subsequent data analytical processing. These outcomes underline the need for continued research into technological robustness and more reliable long-term digital monitoring solutions.

A critical insight relates to the use of augmented and virtual reality as analytical tools. Effective application requires a shared conceptual understanding across all project stakeholders. The project experience revealed substantial discrepancies: technical interfaces were bridged but not interoperable be solved, and the inclusivity of AR and VR ranged from highly instrumental to playful or illustrative rather than technical that limit the acceptance of integration and decision tool as Nadine Damianova et al. (2025) mentioned. It provides an advantage for quick results in communication and meetings, disadvantaging in technical translation. Such divergences limited their potential as consistent tools for environmental analysis and optimisation. Moreover, AR and VR environments may introduce gamification dynamics, whose influence on problem-solving and decision-making remains unclear. Whether such effects support or undermine analytical clarity warrants dedicated future investigation.

Overall, these observations highlight that digital operationalisation - particularly when distributed across institutions, sectors, and international boundaries - remains one of the most significant challenges for implementing Digital Shadows in high-rise environments.

6.1.5 Key Findings of Cross-Site Reflections

The hybrid combination of controlled experimental conditions in TestBed 02 and real-

scale conditions in Tonkin 2 enabled a comparative synthesis across scales and typologies through chapter 5 and the research methodologies. While TestBed 02 allowed for precise measurements, iterative adaptation, and methodological refinement - related to neighbourhood interference - Tonkin 2 provided insights into the constraints of large high-rise structures embedded within complex administrative and institutional environments. In this context, scale becomes an obstacle: static datasets such as BIM and 3D models, real-time sensor data recorded at five-minute intervals, building management procedures, and international cooperation workflows behave markedly differently when transferred from a controlled testbed to an operational residential tower - and from remote distance.

The methodological approach adopted in this work combined perspectives from on-site experimentation, multi-scalar monitoring, qualitative field observation, and interdisciplinary collaboration between Vietnamese and German stakeholders. This hybrid concept proved essential for understanding the interplay between material, ecological, technological systems and human behaviour in a rapidly densifying metropolis. At the same time, the approach revealed a number of structural, technical, and organisational limitations that affect both the feasibility and the long-term reliability of such ambitious and complex urban research.

By linking and observing the three urban scales - Meso, Micro, and Nano - together with system-based insights, the methodology of circular and regenerative cities enabled a deeper understanding of urban metabolic processes, an analogy to current research by Zobra et al. (2025) about urban metabolism and its implications about a Social Development Goals framework within developing countries - a case study that is feasible of applying to emerging countries as well.

6.2 Towards a Vision

Reflecting the key findings adapted to the current TestBed Tonkin 2, then urban metabolism on nano scale repositions the Tonkin 2 to the linear metabolism as shown in figure 6.1. Instead seen through the lens of this dissertation, the palm-ant symbiosis described in Chapter 5.3.2 exemplifies the type of decentralised, self-regulating, and mutually reinforcing logic that future Smart Urban Areas must adopt. This relationship mirrors the conceptual model of the Adaptive Node: local resource circulation, micro-habitat establishment, decentralised operation, and responsive relocation under changing conditions after incremental valuation. In contrast to the technological systems described in this work - many of which exhibited corrosion, data instability, or failure - the biological system demonstrates robustness and minimal maintenance requirements. As such, it provides a compelling natural analogue for designing resilient high-rise infrastructures capable of supporting localised feedback loops within

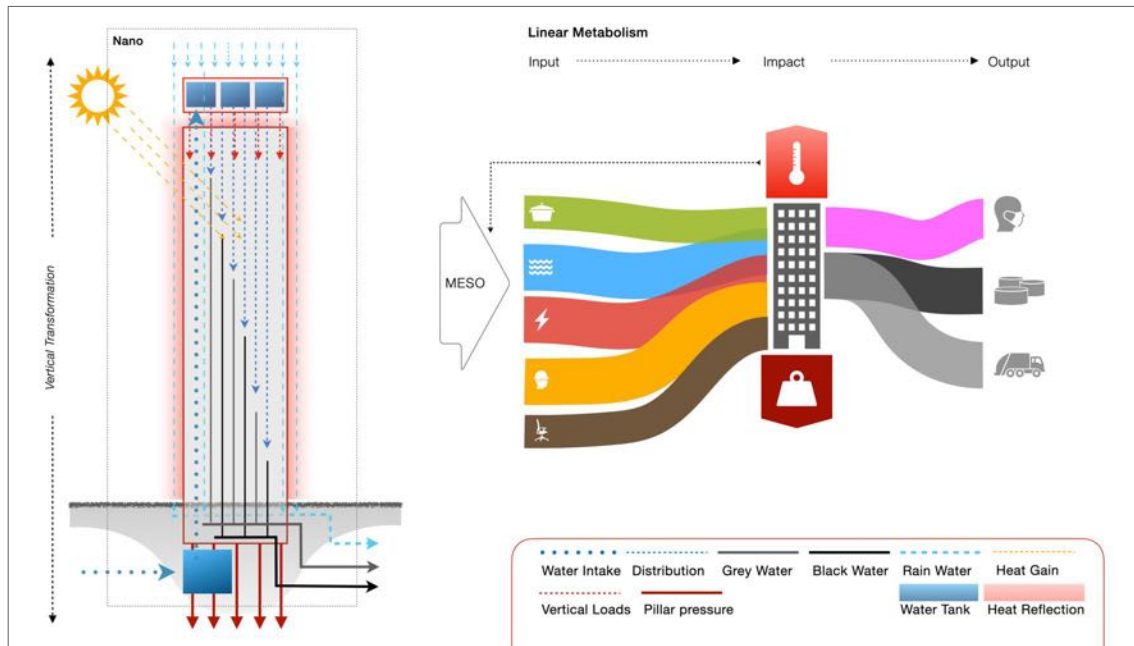


Figure 6.1: Linear Metabolism

built environments. Analogous principles can be found in scientific discourse on regulatory processes, ecological cycles, and regenerative urban metabolism. Figure 6.2 sketches this process on the nano-meso scale of the building, framed here as a high-rise organism. Drawing on the empirical and observational insights generated throughout this work, the chapter seeks to advance the research question by revisiting Figure 1.2 from Chapter 1. The comparison suggests that high-rise buildings should be understood in some manner similar to cruise ships - complex systems capable of managing a wide spectrum of operational functions - yet anchored to a site and integrated into the surrounding micro- and meso environment. In other words cruise ships represent a mature typology of closed-loop environmental management systems. High-rises, by contrast, remain structurally similar but operationally underdeveloped in this regard. Although contemporary high-rise developments already share many features traditionally found on cruise ships, whereas the latter operate under stricter regulatory frameworks and regulations of the International Maritime Organization, requiring on-board membrane (MBR) filtration for wastewater. This parallel aligns with the transfer concept explored in Chapter 5.4, where the membrane-based treatment unit (WA-MBR-TB225 unit) is introduced as a viable contribution for tropical high-rise environments. The objective behind both approaches - cruise ships and Adaptive Nodes - is similar: to treat and reuse water. Adaptive Node Metabolism takes the generative context further ahead in order to cool through vegetated systems, thereby reducing the overall heat load of buildings and in extend urban areas. This system depicted is not yet represented in high-rise building standards, which restricts the functional capacities of such structures. The Adaptive

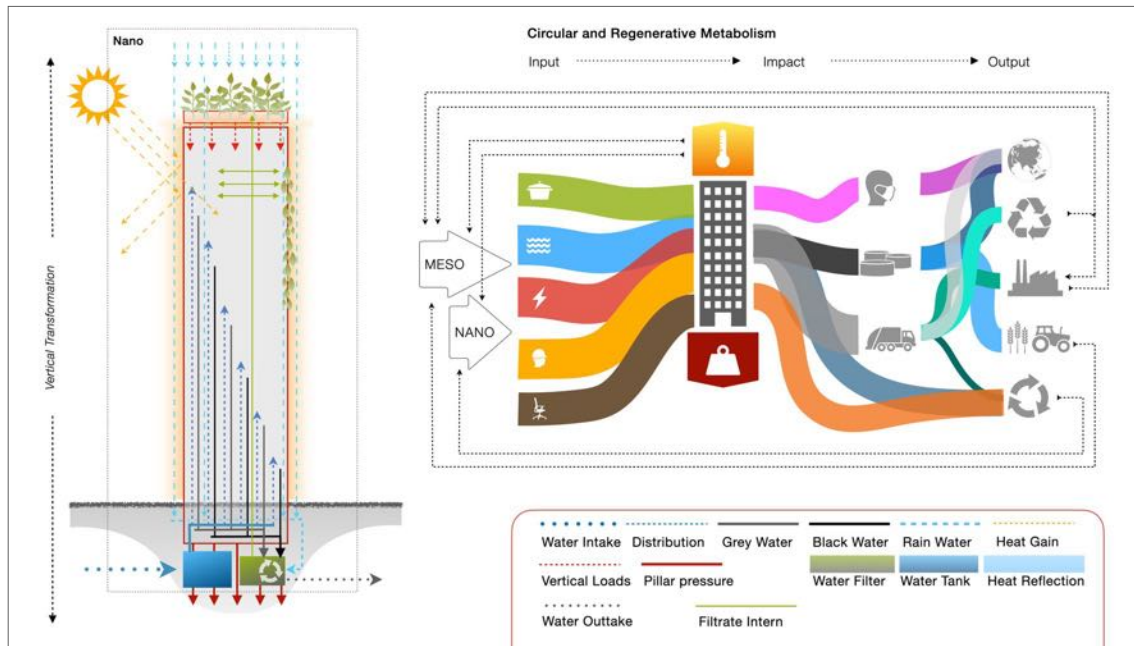


Figure 6.2: Circular and Regenerative Metabolism

Node approach attempts to expand these capabilities.

On the nano scale, the verticality of the high-rise offers opportunities to stack functions, resulting in layered vertical dependencies and mutually reinforcing systems that are more efficiently organised in the vertical than in the horizontal arrangement.

Comparable to a product - whether a car or a watch - the Adaptive Node operates as a holistic urban puzzle piece. Through its vertically applied vegetation, it functions as a cooling fin, moderating facade temperatures and influencing the immediate microclimate, especially at ground level. Figure 6.3 sketches the Adaptive Node concept by stacking the functions derived from the research findings into a vertical cross-section of the high-rise. One possible configuration clusters 10-12 floors into a vertical neighbourhood unit, where intermediate sky gardens ensuring horizontal cross-ventilation, circulation, and communal space. These living clusters sit above a podium zone housing parking, retail, and technical equipment. A central element of this model reflects the elevation of functional areas above ground level. By avoiding investments for basement constructions, this approach reduces the need for extensive soil excavations, deep piling, waterproofed concrete besides mechanical ventilation equipment for parking and technical spaces. Instead lifting these functions enables natural ventilated parking with daylight access, and reducing operational maintenance and safety burdens. A local example for such spatial organisation can be observed in the Seasons Avenue Complex in Hanoi's Ha Dong district, where lower floors provide car and motorbike parking while the higher located apartment towers are vertically separated by a sky garden for the residential community. Besides vertical attached vegetated facades around the parking floors, the horizontal vegetated transition zone

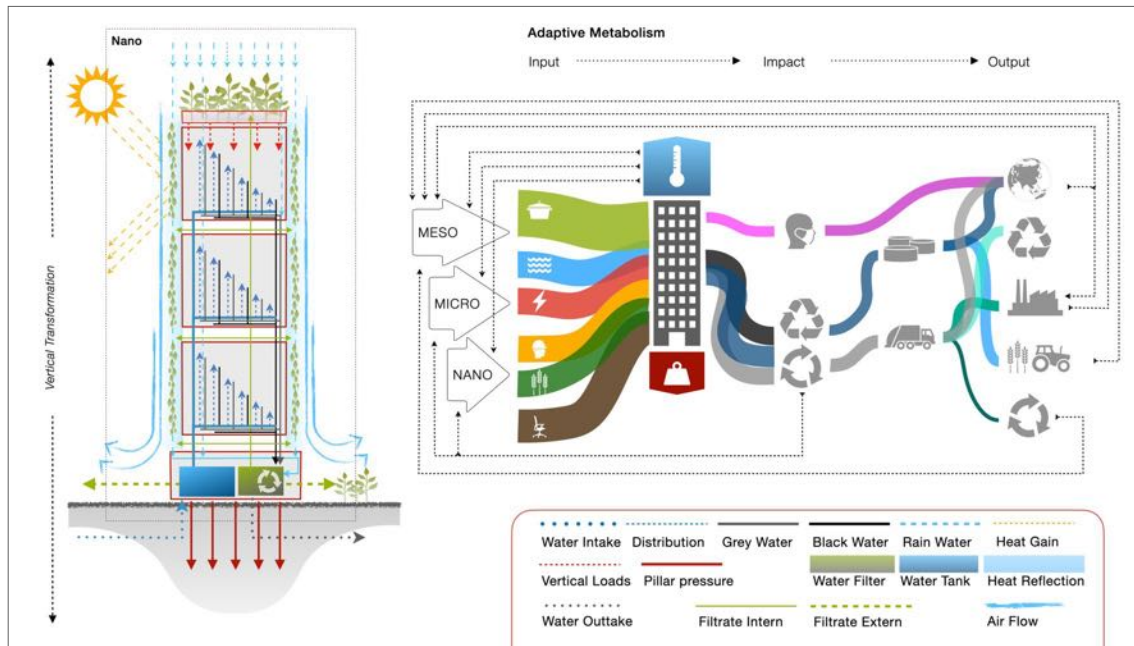


Figure 6.3: Adaptive Node Metabolism

functions as both an environmental buffer and a social interface, reminiscent for elevated infrastructural layers that support climate positive performance, spatial quality, and functional efficiency within urban areas. Recent climate projections for Vietnam indicate rising sea levels and associated ground subsidence and inundation risks in Hanoi and especially Ho Chi Minh City. The Adaptive Node model anticipates these developments, similar to 'Intensive Buildings' described by Ken Yeang from Malaysia, by positioning high-rise buildings as elevated, operative, and resilient structures capable of withstanding future climatic (predictable or unpredictable) circumstances. Beyond these adaptive qualities, the Adaptive Node integrates the capacity to recycle both organic and inorganic return flows - wastewater and solid waste - at building level, thereby reducing burdens placed on the district system. The building envelope, conceived as a second skin equipped with vertical vegetation and irrigation, further contributes to air filtration and microclimatic modulation. In dense high-rise clusters, such cumulative effects strengthen urban resilience by reducing environmental loads transferred back into the meso-scale system and by enabling localised coupling of resource flows. Findings from the research analysis conducted in the bachelor thesis from SUA project colleague Flemming Eismann on climatic impacts of vertical greening in the SUA area confirm that a comprehensive greening scenario, especially the horizontal vegetation, yields overall positive impacts.

Beyond vertical vegetation, the greatest untapped potential for cooling effects and biodiversity enhancement lies on the rooftops of vegetated high-rises. In the research area where Tonkin 2 is located, each tower provides approximately 1,000 m² of roof area, representing a largely underestimated spatial resource - if technical equipments

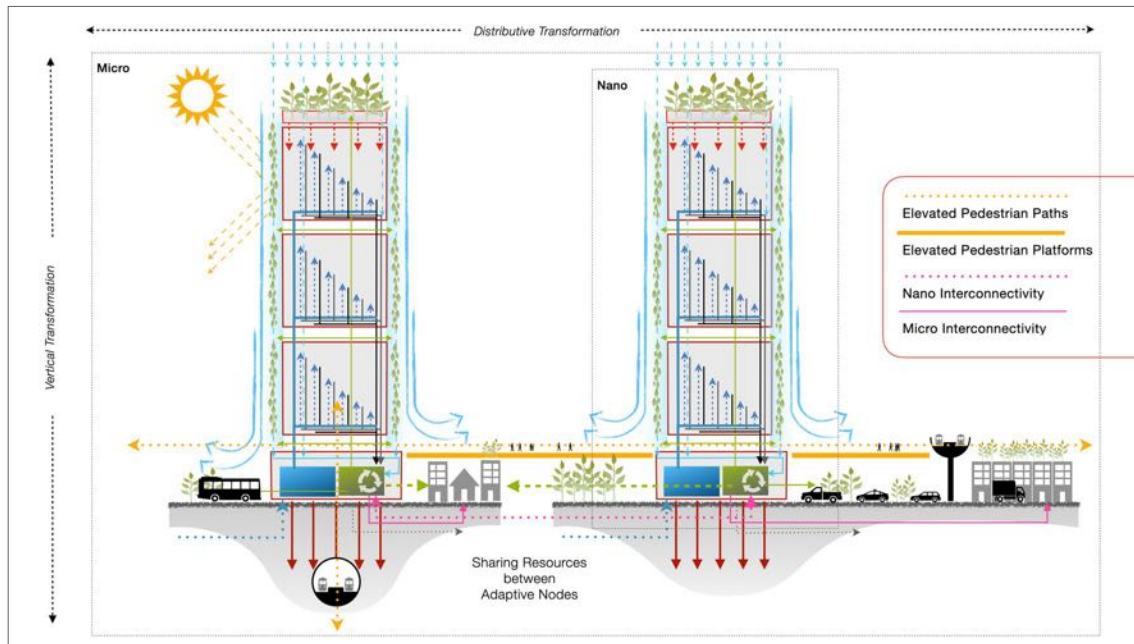


Figure 6.4: Distributive Transformation

are relocated to basement or lower levels. Indeed at the scale of the Hanoi Smart City development, which combines 50 high-rise towers, an estimated cumulative horizontal green area of 70,000 - 80,000 m² becomes feasible. This corresponds to roughly one fifth of the surface area of Thong Nhat Park (0.5 ha) in Hanoi's Hai Ba Trung district.

When understood as a connected system, such elevated and horizontal arranged green areas have the potential to significantly improve thermal comfort, support urban habitats, and moderate microclimatic conditions at both the district and close-by neighbourhood level. In a broader context, the integration of accessible and visible green spaces (elevated parks) also contribute to comfort living, outdoor quality, and safety, besides creating local jobs and in the long-term stimulating property values. A valuable example is the high line in New York City, previous elevated tracks revived into a walkable strip intertwined with the city's fabric. Figure 6.4 illustrates such logic by exemplify two Adaptive Nodes operating independently yet interconnected through shared return flows, supporting the distributed network logic outlined in Chapter 2.4 while strengthening resilient factors for the urban area on the micro scale. In further extension, the MUNA approach discussed in Chapter 2.5 finds its thesis, where vertical and horizontal aligned circulation in urbanity merges at specific congestion locations, in that case the adaptive nodes. Supported by available technologies and knowledge on potential urban flooding while incorporating the strategies from MUD and TOD, such methods reinforces the conceptualisation of districts as active, distributive urban organisms. Raised pedestrian platforms enable the separation of people from ground level traffic and create safe, ventilated mobility corridors between

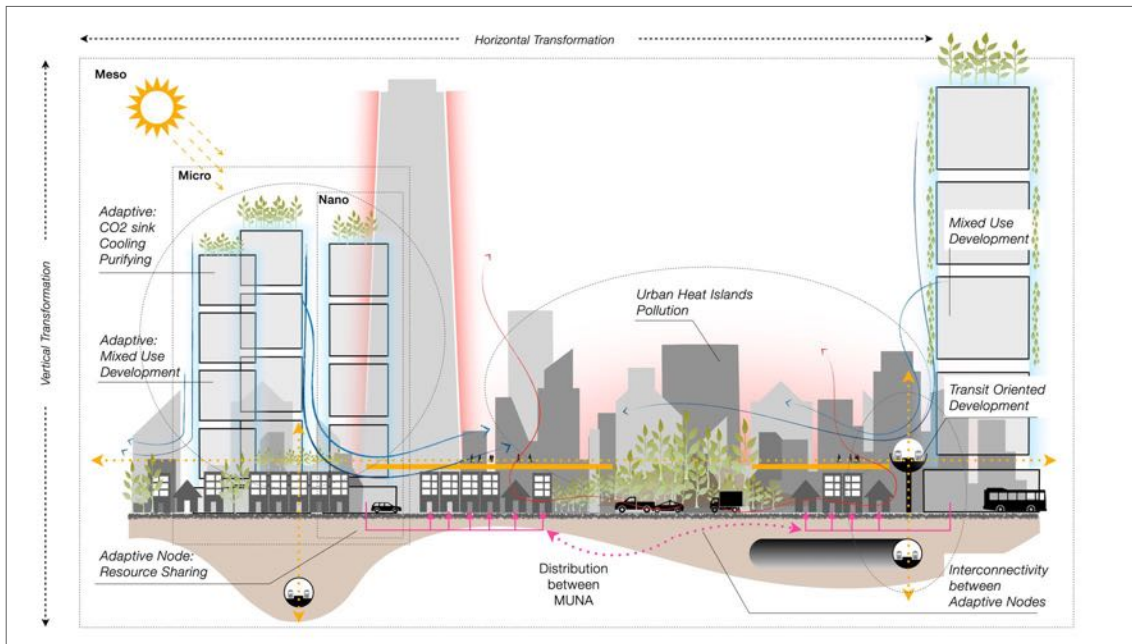


Figure 6.5: Distributive Transformation within Megacities

nodes and transport interfaces - a meaningful proposition for Hanoi, a city facing significant air-pollution challenges. Ultimately, Figure 6.5 indicates, in a broader sense, how modern district planning that incorporates Adaptive Nodes, as well as MUD and TOD principles, can consolidate horizontal and vertical movement flows, diversify functions, and establish climatically active zones within the urban fabric. These zones act as climate-positive (CO₂ sink holes) islands that strengthen the resilience of the overarching meso-scale system. To some critics, such an approach may appear utopian, particularly in light of land-use and property-right regulations that often constrain or even prevent integrated spatial strategies of this kind. However, a broader perspective on megacities reveals that they are not monolithic settlements, but rather historically grown, formally planned, and in some cases informally developed areas. Urban districts and residential areas function as settlements within settlements systems embedded within larger systems. As a result, cities frequently expand as horizontal agglomerations that progressively affect surrounding natural landscapes and especially valuable farmland. Almost machine-like, and in a literal sense, megacities can be pictured as vast machines, permeated by infrastructure and controlled by IoT and ICT technology. The current IoT and ICT developmental trend strongly adheres to this trajectory. If this trajectory is taken to its extreme, it echoes speculative visions such as Arthur C. Clarke's city of Diaspar in his novel *The City and the Stars*, where urban life becomes fully enclosed, technologically controlled, and detached from ecological surroundings. In contradiction, alternative theoretical positions - such as those articulated by Fred Scharmen about NASA and RAND (chapter 2.3) - conceptualise cities (interstellar) as interconnected settlements, human

centered, where the building structure of the city establishing the necessary security and quality of life to ensure a humane existence in future.

Megacities of the coming decades will inevitably become more complex, technologically mediated, dense, and environmentally stressed. Within this context, disruptive yet grounded design approaches that propose alternative urban configurations can meaningfully contribute to more resilient settlement pathways. Such approaches are particularly relevant in rapidly transforming cities such as Hanoi, where developed urban projects and urban heat islands (UHI) currently dominate urban expansion. Disruptive concepts that offer alternative options for urban design processes can contribute positively to urban development, especially how rethinking density, technology, and ecology can be reorganised vertically to enable local production, resource circulation, and social interaction within limited land availability. Key to this is vertical development, which embraces the concepts of the vertical city and vertical production to reorganise functions and circulation locally within a minimal footprint.

6.3 Contribution, Limitation and Outlook

This dissertation should be understood as a contribution to both research and practice. The examined elements - namely the integration of vegetation, decentralised water treatment, monitoring, and adaptations to the building envelope - critically investigate the environmental performance of high-rise buildings in Hanoi as becoming Megacity. Field experiments and multi-scalar analyses demonstrated that resilience does not result from singular technologies but emerges from the interaction of ecological, material, and technological systems functioning as interdependent subsystems. The findings confirm that vegetation, due to its self-regenerative and low-maintenance characteristics, constitutes as one of the most reliable infrastructural components, whereas decentralised water systems and sensor networks require substantial maintaining to operate robustly under the local climate conditions, but offer the most potential. Digital shadows and digital twins must be regarded as integral tools for communication and building management.

This work contributes to contemporary debates on sustainable urban development by introducing the concept of Adaptive Node Urbanism, which repositions high-rise buildings as active metabolic units capable of steering local resource cycles and contributing to broader urban resilience. The methodological reflections emphasise the necessity of context-sensitive communication and aligning that involve government, institutions, local stakeholders and social needs in account for the constraints and opportunities of rapidly developing urban environments. In further extent this work also contribute to socio-ecological and spatial spaces for community

in high-rises for integral planning of such vertical city structures as Phan My Linh Nguyen (2025) stated in her research. In addition Nina Rappaport (2020) consolidates in 'Vertical Urban Factory' thoughts of urbanity and 'super-urban symbiosis' that align with the visionary approach of chapter 6.2 and the global debate that considers open trends towards collaborative neighbourhood manufacturing, diversify areas and distributive functions in order to create hybrid districts and urban areas rather than siloed urban clusters. Indeed in their 2018 research series 'Extreme Urbanism'³⁶, Willy Müller and Jordi Vivaldi (IAAC and Barcelona Urban Science Lab)³⁷ explored the intricacies of urban planning through the lens of six transport modalities, challenging prevailing paradigms regarding the evolution of megacities. Such developments underline the concept of MUNA and reinforcing resilience factors in parts of Mega Cities will be a supportive element for society.

Although this research outlines clear pathways towards more sustainable integrated high-rise buildings and districts, it also identifies several areas requiring further development. These include long-term monitoring of system resilience, improved technological robustness, and strategies for metabolic integration at the nano and micro scale. Ultimately, the dissertation demonstrates that high-rise development - when guided by holistically systemic design - can move beyond conventional analytical models toward regenerative, adaptive, and contextually grounded forms of urban architecture.

The methodological reflections suggest that future sustainability research in the global South must embrace greater adaptability and longterm engagement paired with local contexts. Field experiments should be complemented by robust maintenance protocols, redundant monitoring strategies, and partnerships with local contractors, suppliers and residents. However, such requirements often conflict with typical three-year research frameworks, which rarely allow sufficient time for iterative refinement, embedded collaboration, or longterm system observation. In the case of the SUA research project, the allocated three years must be understood as an investment in methodological development, on-site adaptation and interface problem-solving to set early benchmarks. The actual qualitative research and subsequent refinement of early findings would require a further three-year period to consolidate the established networks, structures, and investments. Only then can true transdisciplinary collaboration emerge, and only then can results be sufficiently grounded to serve as validated blueprints for dense, climate-stressed metropolitan areas and regions.

The multidimensional design and research approach presented in this work remains a

³⁶ https://issuu.com/willymuller/docs/booklet_issuu-low (20.04.2022)

³⁷ <https://iaac.net/> (19.01.2026)

complex undertaking, yet holds substantial potential to reorient urban development in innovative ways. In many respects, this requires questioning long-standing conventions in regulations, the construction and planning industries besides introducing initially unfamiliar conceptual shifts to open new perspectives to share knowledge. By involving diverse parameters and stakeholders in the earliest phases of project development, negative impact factors can be reduced or prevented, while constructive solutions for collective urban development can be framed. Cost-driven decision-making - i.e. favouring the lowest bidder and the path of least resistance - often results in technological and sustainability disadvantages over the building lifecycle.

A multidimensional mindset instead demands longterm partnerships and a shared understanding to integrate resilience factors as core components of urban areas and district development. This work may serve as a conceptual framework and intellectual stimulus for Megacity development of the global South - especially within the equatorial belt between 30° northern and 20° southern latitude, the region expected to host the fastest-growing megacities by 2050. Based on the UN urbanization prospects 2025³⁸, the South-East-Asia region accumulates the majority of megacities. The findings can also be transferred to similar climatic zones globally, where they should be adapted to local conditions and implemented accordingly.

For a further development of collaboration with the Southeast Asian region (SEA), the establishment of a research and development centre in Vietnam - endorsed by Germany or Europe - would be a viable and strategic option between both countries. Singapore as technological leader in the region propagate tendencies, Vietnam instead rises to an influential - manufacturing and IT - powerhouse that needs to define itself. Such a centre could serve as a hub for anchoring, testing, and advancing scientific knowledge, technologies, and expertise in the region, while enabling reciprocal exchange and complementary development. It would form an independent bridge of experience, knowledge, and technical capacity from which both sides could benefit, and where insights generated in the region could be centrally consolidated and maintained. A smart step towards sustainable strategies and goals that can be solved together in a currently new polarised world.

³⁸ <https://www.un.org/development/desa/pd/world-urbanization-prospects-2025> (30.11.2025)

References

- Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landscape and Urban Planning*, 100(4), 341–343.
<https://doi.org/10.1016/j.landurbplan.2011.02.021>
- Angelidou, M. (2014). Smart city policies: A spatial approach. *Cities*, 41, S3–S11.
<https://doi.org/10.1016/j.cities.2014.06.007>
- Asian Development Bank. (2009). Water vital for Vietnam's future. ADB.
<https://www.adb.org/publications/water-vital-viet-nams-future>
- Azad, N. M., & Samarakoon, S. M. S. M. K. (2021). Utilization of Industrial By-Products/Waste to Manufacture Geopolymer Cement/Concrete. *Sustainability*, 13(2), 873. <https://doi.org/10.3390/su13020873>
- Bai, X., McPhearson, T., Cleugh, H., Nagendra, H., Tong, X., & Zhu, Y.-G. (2016). Linking urban sustainability indicators to policy and planning agendas. *Current Opinion in Environmental Sustainability*, 23, 17–23.
<https://doi.org/10.1016/j.cosust.2016.01.007>
- Baran, P. (1964). On Distributed Communications: I. Introduction to Distributed Communications Networks. RAND Corporation.
https://www.rand.org/pubs/research_memoranda/RM3420.html
- Batty, M. (2013). *The New Science of Cities*. MIT Press.
- Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Portugali, Y. (2012). Smart cities of the future. *The European Physical Journal Special Topics*, 214(1), 481–518.
<https://doi.org/10.1140/epjst/e2012-01703-3>
- Berardi, U. (2016). The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. *Energy and Buildings*, 121, 217–229.
<https://doi.org/10.1016/j.enbuild.2015.12.022>
- BMI. (2020). Musterbauordnung (MBO). Ministry of the Interior.
<https://www.bauministerkonferenz.de/Dokumente/42323530.pdf>
- Bui, N. T. (2022). Willingness to Pay for Improved Urban Domestic Water Supply in Hanoi. *Water*, 14(14), Article 2161.
<https://doi.org/10.3390/w14142161>
- Cao, H., et al. (2023). Urban Resilience: Concept, Influencing Factors and Improvement. *Frontiers in Business, Economics and Management*, 9(1), 343–346
- Calthorpe, P. (1993). *The Next American Metropolis: Ecology, Community, and the American Dream*. Princeton Architectural Press.
- Caprotti, F., & Cowley, R. (2017). Smart urbanism in transition: An international research agenda for urban transitions. *Urban Studies*, 54(12), 2644–2661.

- Campiotti, C. A., Chen, H., & Lee, S. J. (2022). Integrated urban water management: A case study of rainwater harvesting in cities. *Journal of Urban Systems and Environmental Engineering*, 45(2), 112-130
- Cervero, R. (1998). *The transit metropolis: A global inquiry*. Island Press.
- Cervero, R., & Murakami, J. (2009). Rail and property development in Hong Kong: Experiences and extensions. *Urban Studies*, 46(10), 2019–2043.
- Cheng, D., Reiner, D.M., Yang, F. et al. Projecting future carbon emissions from cement production in developing countries. *Nat Commun* 14, 8213 (2023).
<https://doi.org/10.1038/s41467-023-43660-x>
- Curtis, C., Renne, J. L., & Bertolini, L. (Eds.). (2009). *Transit Oriented Development: Making It Happen*. Ashgate.
- Da Nang Water Supply Joint Stock Company [DAWACO]. (2023). High growth prospects for Vietnam’s water supply companies.
<https://dnphawaco.vn/en>
- Damianova, N., Berrezueta Guzman, S. (2025). Serious games supported by virtual reality—Literature review. *IEEE Access*, 1-1, 11
<https://doi.org/10.1109/ACCESS.2025.3544022>
- Elliott, M., Foster, T., & MacDonald, M. (2021). Multiple water source use in low- and middle-income countries: A systematic review. *npj Clean Water*, 4(29), 1–10.
<https://doi.org/10.1038/s41545-021-00121-6>
- Evola, G., & Lucchi, E. (2024). Thermal performance of the building envelope: Original methods and advanced solutions. *Buildings*, 14(8), 2507.
<https://doi.org/10.3390/buildings14082507>
- Feuerwehrverband. (2022). Sprinkler systems in residential high-rise buildings in Germany. *German Fire Protection Journal*, 78(11), 845–852.
- Friedman, Y. (1970). *Utopies Réalisables*. Paris: Éditions de l’*éclat*.
- Gomes, Kelly & Carvalho, Monica & Diniz, Daniel & Abrantes, Rafael & Branco, Michel & Junior, Paulo. (2019). Carbon emissions associated with two types of foundations: CP-II Portland cement-based composite vs. geopolymer concrete. *Matéria* (Rio de Janeiro).
<https://doi.org/10.1590/S1517-707620190004.0850>
- Graham, S., & Marvin, S. (2001). *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition*. Routledge.
- Grant, J. (2002). Mixed Use in Theory and Practice: Canadian Experience with Implementing a Planning Principle. *Journal of the American Planning Association*, 68(1), 71–84.
<https://doi.org/10.1080/01944360208977192>
- Hamann, H., Divband Soorati, M., Heinrich, M. K., et al. (2017). *Flora robotica: An architectural system combining living natural plants and distributed robots*.

- arXiv.
<https://doi.org/10.48550/arXiv.1709.04291>
- Hansen, J. P., Jaatun, M. G. (2020). Security and privacy challenges in public cloud-based project management software. *Computers & Security*, 89, 101658.
<https://doi.org/10.1016/j.cose.2019.101658>
- Hall, P., & Pfeiffer, U. (2000). *Urban Future 21: A Global Agenda for Twenty-First Century Cities*. Routledge.
- Hall, R. E., Bowerman, B., Braverman, J., Tayler, J., Todosow, H., von Wimmersperg, U. J. (2000). The vision of a smart city.
- Hoppenbrouwer, E., & Louw, E. (2005). Mixed-use development: Theory and practice in Amsterdam's Eastern Docklands. *European Planning Studies*, 13(7), 967–983
- Hong, A. N., & Kim, M. J. (2023). Large-scale urban transformation and socio-spatial restructuring in Hanoi's new urban areas. *Cities*, 136, 104226.
<https://doi.org/10.1016/j.cities.2023.104226>
- Hong, T. M., & Kim, A. M. (2023). Urban transformation in Hanoi: Planning new urban areas in a transitional economy. *Journal of Urban Affairs*, 45(2), 345–367.
<https://doi.org/10.1080/07352166.2022.2104827>
- Jahnkassim, P. S., & Ip, K. (2014). Linking bioclimatic theory and environmental performance in tropical high-rises of Ken Yeang. International Islamic University Malaysia / University of Brighton.
- Jiang, B., & Huang, J.-T. (2021). A new approach to detecting and designing living structure of urban environments. arXiv.
<https://doi.org/10.48550/arXiv.2104.04131>
- ISO (2019). ISO 37122: Sustainable cities and communities — Indicators for Smart Cities. International Organization for Standardization.
- ITU (2020). Y.4903/L.1603: Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals. International Telecommunication Union.
- Karakus, S., Kuester-Campioni, T., Nguyen Xuan, T. (2025). Potentials and challenges in the creation and utilisation of Building Digital Shadows - Key learnings from case studies in Vietnam [Manuscript submitted for publication]. MDPI
- Kavana, G. B. (2023): Miyawaki Forest Report, Researchgate, 2-3
<https://doi.org/10.13140/RG.2.2.10680.93441>
- Kenworthy, J. R. (2006). The eco-city: Ten key transport and planning dimensions for sustainable city development. *Environment and Urbanization*, 18(1), 67–85.
- Kerzner, H. (2017). *Project management: A systems approach to planning, scheduling, and controlling* (12th ed.). Wiley.
- Klein, P. M., Coffman, R., 2015. Establishment and performance of an experimental

- green roof under extreme climatic conditions. *The Science of the total environment* 512-513, 82–93.
<https://doi.org/10.1016/j.scitotenv.2015.01.020>
- Klotz, L. (2020). *Sustainable Building Systems and Construction for Designers*. Cengage Learning.
- Koch, F., & Vu, H. T. (2020). Urban heat and social vulnerability in Hanoi: A spatial planning perspective. *Urban Climate*, 34, 100685.
<https://doi.org/10.1016/j.uclim.2020.100685>
- Koch, F., & Vu, H. T. (2020). Urban heat and social vulnerability in Hanoi: A spatial planning perspective. *Urban Climate*, 34, 100685.
<https://doi.org/10.1016/j.uclim.2020.100685>
- Koch, M., & Vu, H. (2020). Smart Urban Areas in Vietnam? Critical reflections on digital planning frameworks. *Asia-Pacific Journal of Urban Studies*, 33(1), 56–72.
- Koch, T., & Vu, T. T. (2020). Urban growth and exclusion in Hanoi: Displacements in the name of development. *Geoforum*, 117, 61–70.
<https://doi.org/10.1016/j.geoforum.2020.09.013>
- Kumar, A. M., Sandhya, G. M., Anush, A., (2023). Miyawaki method of forest plantations - bane or boon, *My Forest*, 59 (Issue No. 3), 55, P. 7f
- Kurniati, O., Surjamanto, W., Sugeng, T. (2024). Several façade types for mitigating urban heat island intensity, *Building and Environment*, Volume 248,
<https://doi.org/10.1016/j.buildenv.2023.111031>
- Le, D. T., Hoang, N. P., & Nguyen, T. T. (2022). Green infrastructure and climate adaptation strategies in Hanoi’s urban planning. *Sustainable Cities and Society*, 76, 103479.
<https://doi.org/10.1016/j.scs.2021.103479>
- Le, Q., et al. (2022). Microclimate resilience in high-density developments: Challenges in Vietnamese urbanization. *Environmental Sustainability Review*, 28, 105-121.
- Le, H., Tran, N., & Vu, Q. (2022). “Smart Cities and Environmental Governance in Vietnam: Between Policy and Practice.” *Cities*, 129, 103796.
- Le, T. D., Ngo, T., & Nguyen, T. H. (2022). Social integration and climate resilience in Vietnam’s new urban areas. *Urban Studies*, 59(8), 1524–1540.
<https://doi.org/10.1177/00420980211040356>
- Leach, M., Raworth, K., & Rockström, J. (2012). Between social and planetary boundaries: Navigating pathways in the safe and just space for humanity. *World Social Science Report 2013: Changing Global Environments*, UNESCO.
- Lehmann, S. (2010). Green Urbanism: Formulating a Series of Holistic Principles. *SAPIENS*, (3), 1–10.
- Lehmann, S. (2014). Low carbon districts: Mitigating the urban heat island with green roof infrastructure. *City, Culture and Society*, 5(1), 1–8.

<https://doi.org/10.1016/j.ccs.2014.02.002>

- Linstone, H. A., & Turoff, M. (Eds.). (2002). *The Delphi method: Techniques and applications*. Addison-Wesley.
- Ludwig, F. (2023). Baubotanik and living architecture: integrating plant growth and structural design. *Sustainable Architecture Review*, 12(4), 225–240.
- Lynch, C. M., Smith, J. R. (2021). The 'productivity paradox' of project management software in research: An institutional perspective. *Research Policy*, 50(6), 104230.
- <https://doi.org/10.1016/j.respol.2021.104230>
- Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, 147, 38–49.
- <https://doi.org/10.1016/j.landurbplan.2015.11.011>
- Ministry of Construction Vietnam. (2016). Circular No. 31/2016/TT-BXD: Classification of apartment buildings. Hanoi.
- Ministry of Construction Vietnam. (2020). QCVN 06:2020/BXD: National technical regulation on fire safety of buildings and constructions. Hanoi.
- Miyawaki A. (1988): Vegetation ecological study for restoration of forest ecosystems. In: Fujiwara K (ed) *A vegetation ecological study for the restoration and rehabilitation of green environment based on the creation of environmental protection forests in Japanese Archipelago*. Inst. Veget. Sci., Inst. Environ. Sci. Technol. Yokohama Natl. Univ., 267–298
- Miyawaki, A. (1999): Creative ecology: restoration of native forests by native trees. *Plant Biotechnology*, 16(1):15–25
- Miyawaki A. (2004): Restoration of living environment based on vegetation ecology: Theory and practice, *Ecological Research* 19(1): 83-90
- Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pralong, F. (2021). Introducing the “15-minute city”: Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities*, 4(1), 93–111.
- Mostafavi, M., & Doherty, G. (Eds.). (2010). *Ecological Urbanism*. Harvard University Graduate School of Design.
- Nazarian, N., Dumas, N., Kleissl, J., Norford, L. (2019). Effectiveness of cool walls on cooling load and urban temperature in a tropical climate, *Energy and Buildings*, Volume 187, 144-162,
- <https://doi.org/10.1016/j.enbuild.2019.01.022>
- Newman, P., & Jennings, I. (2008). *Cities as Sustainable Ecosystems: Principles and Practices*. Island Press.
- Nguyen, P. M. L. (2025). High-rise living: Stimulating social interaction in high-rise apartment buildings. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Eindhoven University of Technology

- Nguyen, T. M., & Harms, E. (2019). Enclaving and exclusion in Vietnam's urban periphery. *City & Society*, 31(2), 305–327.
<https://doi.org/10.1111/ciso.12184>
- Nguyen, T. M., & Harms, E. (2019). Privatized modernity and urban development in Hanoi. *City & Society*, 31(1), 35–58.
<https://doi.org/10.1111/ciso.12147>
- Nguyen, T. M., & Harms, E. (2019). “Urban Aspirations and Segregation in Hanoi’s New Urban Zones.” *Journal of Urban Affairs*, 41(3), 343–360.
- Nguyen, T. T., & Kim, M. S. (2020). Socio-economic factors influencing sustainable urban development in developing countries: A case study of Vietnam. *Journal of Urban Studies and Planning*, 21(4), 345–362
- Odum, H. T. (1971, 2007). *ENERGETIC ORGANIZATION OF SOCIETY*. In *Environment, Power, and Society for the Twenty-First Century: The Hierarchy of Energy* (pp. 281–312). Columbia University Press.
<http://www.jstor.org/stable/10.7312/odum12886.14>
- Ōtaki, Y., Ōtaki, M., Bao, P. N., Nga, T. T. V., & Aramaki, T. (2013). Micro-component survey of residential water consumption in Hanoi. *Water Science & Technology: Water Supply*, 13(2), 469–479.
<https://doi.org/10.2166/ws.2013.029>
- Pham, H. V., Luong, T. A., & Nguyen, H. D. (2023). A classification framework for typical Vietnamese residential building typologies. *International Journal of Building Research & Technology*, 10(1), 55–72
- Pham, T. H., Luu, H. T., & Nguyen, M. T. (2020). Urban air pollution in Hanoi: Status, challenges, and governance responses. *Environmental Science and Policy*, 109, 68–76.
<https://doi.org/10.1016/j.envsci.2020.04.007>
- Pham, T. H., Tran, L. N., & Le, Q. A. (2023). Smart urbanism in Vietnam: Digital governance and spatial restructuring. *Urban Studies*, 60(5), 895–912.
<https://doi.org/10.1177/00420980221118841>
- Pham, T. H., Luu, H. T., & Nguyen, M. T. (2023). Smart infrastructure development in New Urban Areas: evidence from Hanoi. *Urban Technology Studies*, 2(1), 45–61.
- Pham, T., Vu, N., & Dao, M. (2023). “Smart Infrastructure and High-Rise Living in Hanoi: Challenges of Vertical Urbanism.” *Asian Cities*, 18(2), 77–96.
- Phung, V. L., & Nguyen, T. H. (2018). Fire safety regulations in Vietnamese high-rise buildings. *International Journal of Fire Protection Engineering*, 18(3), 210–225
- Pinto, L. (2022). *The unsustainable city: How urban planning has failed us*. Columbia University Press.
- Portugali, J. (2021). *The Smart City and the Complexity of Urban Space*. Springer.

- Price, C., & Littlewood, J. (1964). The Fun Palace [Architectural Proposal]. In Price, C. (Ed.), *Works II* (1999).
- Rappaport, N. (2020). Vertical urban factory, New York, Actar, 432-457
- Sailor, D. J. (2011). A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. *International Journal of Climatology*, 31(2), 189–199.
<https://doi.org/10.1002/joc.2106>
- Schaefer, M., Kuester-Campioni, T., Nguyen Xuan, T. (2024). Data jungle on the roof - how can intelligent green building be achieved?, *GISBusiness*
- Schaefer, M., Kuester-Campioni, T., Nguyen Xuan, T. (2025). Thermal Performance of Roof and Façade Greening Under Summer-Time Heatwave Conditions in Hanoi, Vietnam. *Urban Forestry & Urban Greening*,
<https://doi.org/10.1080/13467581.2025.2584641>
- Scharmen, F. (2019). *Space Settlements*. New York: Columbia Books on Architecture and the City.
- Schmidt, T. S., Zimmermann, M. (2022). Overcoming the challenges of project management software in academic research environments. *Research Management Review*, 27(1), 34–49.
- Schumacher, P., Feringa, J., Wüst, T., & Sawodny, O. (2022). The Adaptive High-Rise D1244: Enabling real-time reconfiguration of structure and envelope. *Frontiers in Built Environment*, 8, 814911.
<https://doi.org/10.3389/fbuil.2022.814911>
- Scrivener, K. L., John, V. M., & Gartner, E. M. (2018). Eco-efficient cements: Potential, economically viable solutions for a low-CO2 cement-based materials industry. *Cement and Concrete Research*, 114, 2–26.
<https://doi.org/10.1016/j.cemconres.2018.03.015>
- Sepasgozar, S. M. E. (2021). Differentiating digital twin from digital shadow: Elucidating a paradigm shift to expedite a smart, sustainable built environment. *Buildings*, 11(4), 151.
<http://dx.doi.org/10.1080/21693277.2024.2387679>
- Sharifi, A., & Yamagata, Y. (2018). Principles and criteria for assessing urban energy resilience: A literature review. *Renewable and Sustainable Energy Reviews*, 60, 1654–1677.
- Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2016). Edge Computing: Vision and Challenges. *IEEE Internet of Things Journal*, 3(5), 637–646.
<https://doi.org/10.1109/JIOT.2016.2579198>
- Statista. (2024). Vietnam: Total population from 2019 to 2024.
<https://www.statista.com/statistics/444912/population-of-vietnam/>
- Singh, C., Saini, G., (2019), Sustainable solution for urban environment: Miyawaki

- Method, *International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)*, Vol.5 (Issue 4), P.3ff
- Shenhar, A. J., & Dvir, D. (2007). *Reinventing project management: The diamond approach to successful growth and innovation*. Harvard Business School Press.
- Sk. Riad, M., Kuester-Campioni, T., Daus D., (2022), *Sustainable Urban Mobility Transport Oriented City*, ADL Cutter,
<https://doi.org/10.1109/IJOT.2016.2579198>
- Susca, T., Gaffin, S. R., & Dell'Osso, G. R. (2011). Positive effects of vegetation on urban microclimate: A meta-analysis. *Environmental Research*, 111(3), 464–475.
<https://doi.org/10.1016/j.envres.2011.05.007>
- Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development*. World Bank Publications.
- Talen, E. (2005). *New urbanism and American planning: The conflict of cultures*. Routledge
- Thai, H. M. H., Khuat, H. T., & Kim, H. M. (2021). Urban form, the use of ICT and smart cities in Vietnam. In *Smart Cities for Technological and Social Innovation* (pp. 137-156).
- Thai, T. V., Nguyen, T. H., & Pham, N. T. (2021). Smart cities in Vietnam: A socio-political critique. *Journal of Urban Technology*, 28(4), 3–25.
<https://doi.org/10.1080/10630732.2020.1810762>
- Thai, V. D., Le, N., & Truong, M. (2021). “ICT-Centric or Human-Centric? Re-evaluating Smart City Practices in Vietnam.” *Journal of Urban Technology*, 28(4), 3–22.
- UN-Habitat. (2020). *World Cities Report 2020: The Value of Sustainable Urbanization*. United Nations Human Settlements Programme.
- UN-Habitat. (2022). *Urban development and climate change adaptation in Southeast Asia*. United Nations Human Settlements Programme.
- United Nations. (2018). *World Urbanization Prospects: The 2018 Revision*. UN Department of Economic and Social Affairs, Population Division.
- Vanolo, A. (2016). Is there anybody out there? The place and role of citizens in tomorrow’s smart cities. *Futures*, 82, 26–36.
<https://doi.org/10.1016/j.futures.2016.05.010>
- Waibel, M., Nguyen T. T. T., Nguyen, Q. M. & Pham, T. H. H. (eds.) (2024). *Handbook for Green Housing and Healthy Living – 2nd updated edition*. Construction Publishing House, Hanoi, 130 pages, eISBN: 978-604-82-8190-8,
<https://doi.org/10.23689/figeo-6338>
- Waters, J. (2016). *ACCESSIBLE CITIES: FROM URBAN DENSITY TO*

- MULTIDIMENSIONAL ACCESSIBILITY. In D. SIMON (Ed.), *Rethinking sustainable cities: Accessible, green and fair* (1st ed., pp. 11–60). Bristol University Press.
<http://www.jstor.org/stable/j.ctv47w457.10>
- Watson, V. (2009). "The planned city sweeps the poor away...": Urban planning and 21st century urbanisation. *Progress in Planning*, 72(3), 151-193.
<https://doi.org/10.1016/j.proplan.2009.06.002>
- Wilkinson, C. (2012). Social-ecological resilience: Insights and issues for planning theory. *Planning Theory*, 11(2), 148–169.
<https://doi.org/10.1177/1473095211426274>
- Wong, G., Lee, H., & Chen, J. (2021). The holistic systems approach to building energy efficiency. *Journal of Sustainable Building Design*, 28(2), 187-204
- World Bank. (2019). *East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth*.
- Yeang, K. (1994). *The Skyscraper: Bioclimatically Considered – A Design Primer*. Wiley-Academy.
- Yeang, K. (1996, 2006). *EcoDesign: A Manual for Ecological Design*. Wiley-Academy.
- Yeang, K. (2006). *The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings*. Prestel.
- Yeang, K. (2011). *Eco-mimicry in Architecture and Urbanism: Creating Spaces Inspired by Nature*. RIBA Journal.
- Yeang, K. (2011). *Biomimicry: The new science of building*. John Wiley & Sons.
- Zaman, A. U., & Lehmann, S. (2011). Urban Growth and Waste Management Optimization towards 'Zero Waste City'. *Cities*, 36, 58–67.
<https://doi.org/10.1016/j.cities.2013.10.002>
- Zhu, S., Wang, P., Lou, W., et al. (2024). Resilience-oriented planning of urban distribution system source-network-load-storage in the context of high-penetrated building-integrated resources. *Buildings*, 14(5), 1197.
<https://doi.org/10.3390/buildings14051197>
- Zorba, R., Malarvizhi, G. (2025) Urban metabolism: a dual-perspective case study and its implications in the urban political economy of developing nations for an effective SDG framework. *Front. Sustain. Cities*. 7:1538006.
<https://doi.org/10.3389/frsc.2025.1538006>
- Zuojiang L., Guangyao L., Kuizhen F., (2025) Carbon emissions assessment of concrete and quantitative calculation of CO2 reduction benefits of SCMs: A case study of C30-C80 ready-mixed concrete in China, *Case Studies in Construction Materials*, Volume 22
<https://doi.org/10.1016/j.cscm.2025.e04287>

Appendices

A. Appendix: Tables

A.1. Thermal Imaging and Facade Orientation

A.2. Wall Assembly Material Breakdowns (T2)

A.3. Wall Economics and Emissions (T2)

A.4. Upscaling to the VSC and on national Level

A.5. Sensor Placement

A.6. Filtration Capacity Calculations and Electricity Consumption (TB2)

B. Appendix: Technical Drawings

B.1. TestBed 1

B.2. TestBed 2

B.3. Water Infrastructure

B.4. Digital Shadow in AR and VR

C. Appendix: Recommendations to local Partner

C.1. Greening Parkdeck 4

C.2. Construction Material Potentials

C.3. Villa 2.0

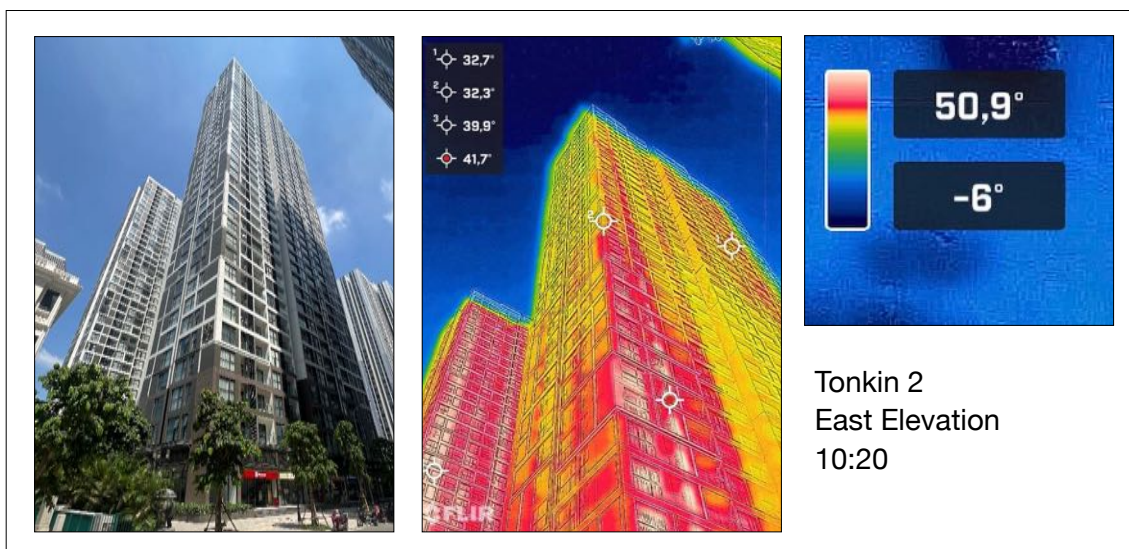
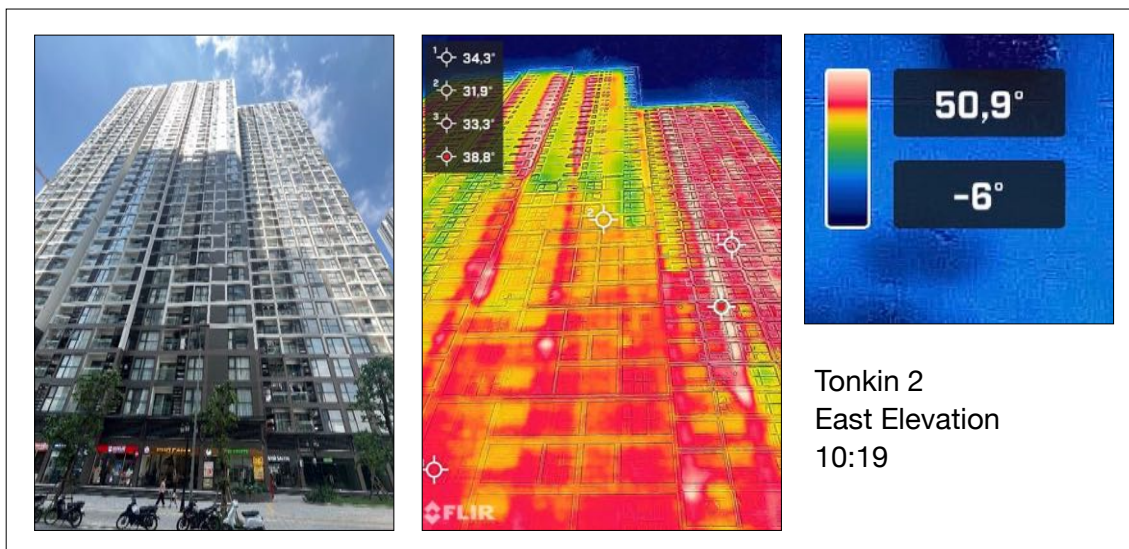
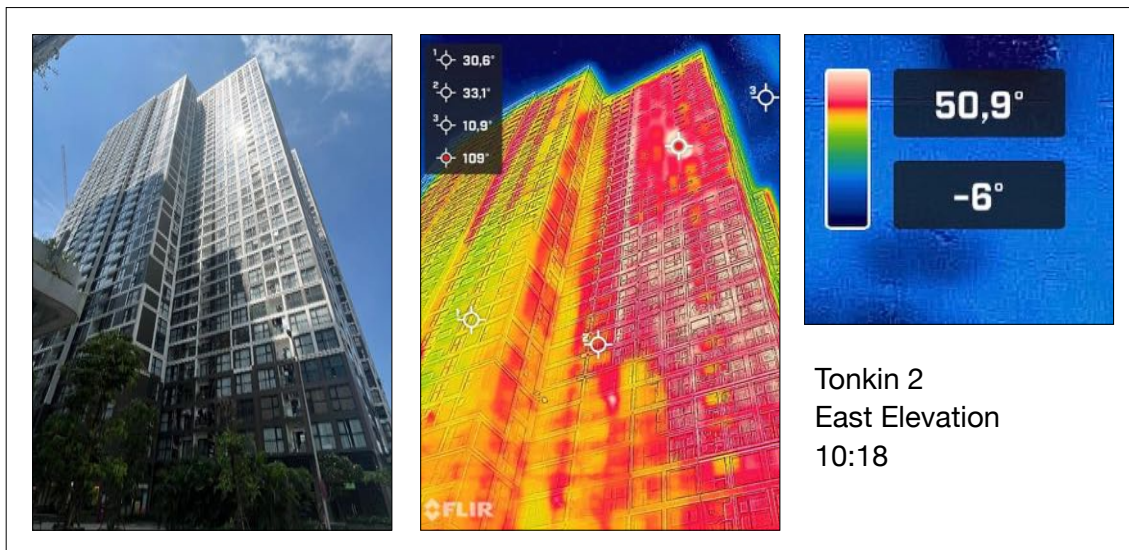
D. Appendix: Impact Factors - TU Dortmund University Campus

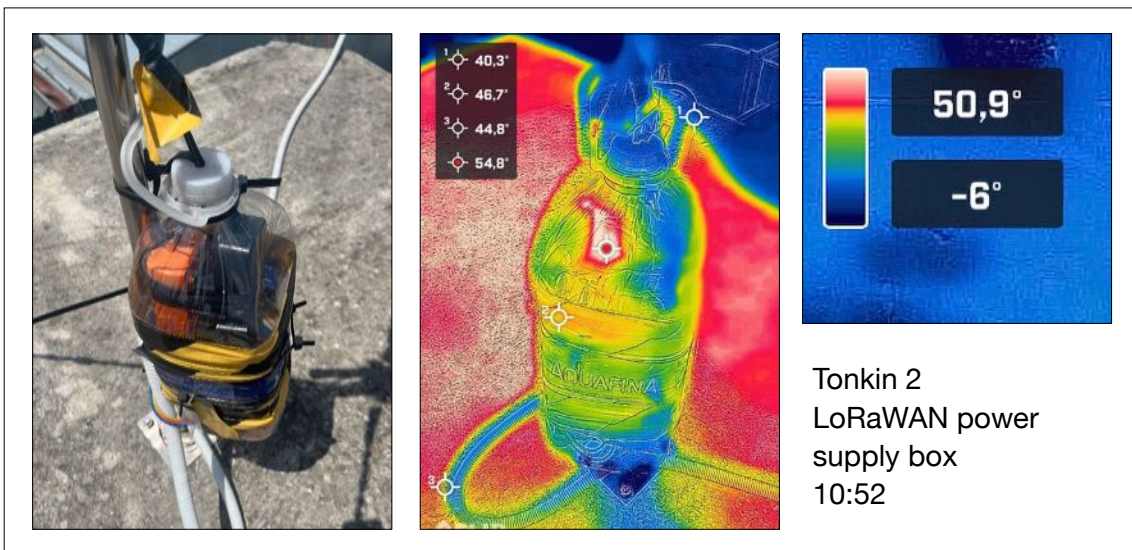
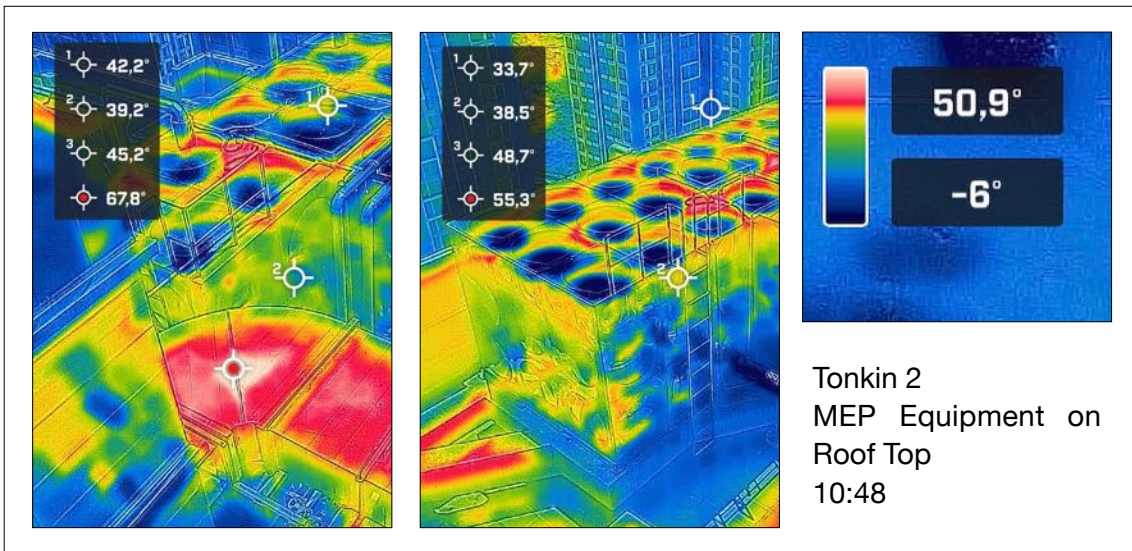
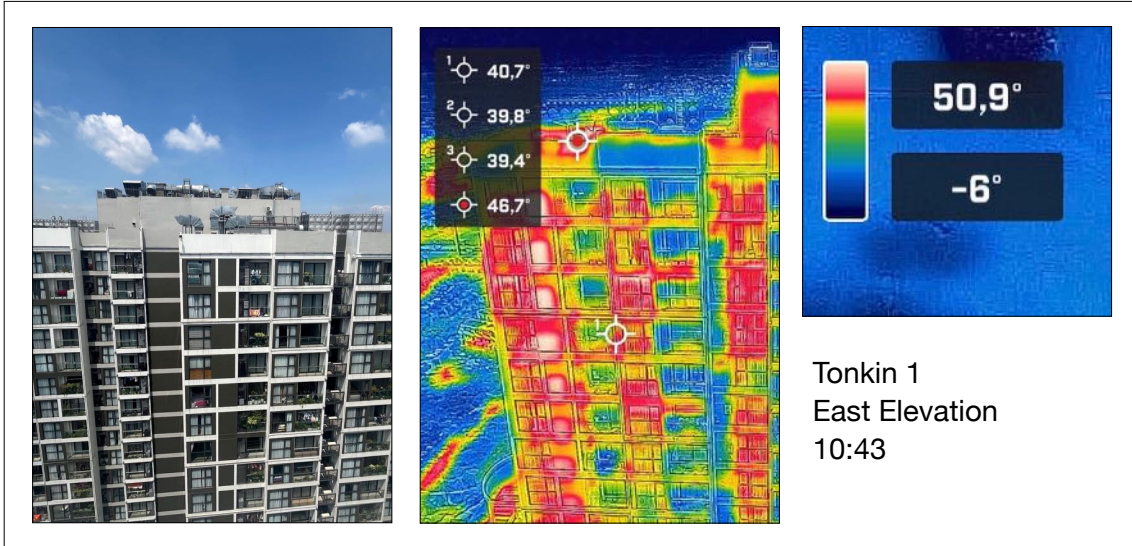
D.1. Garden(s) of Refuge

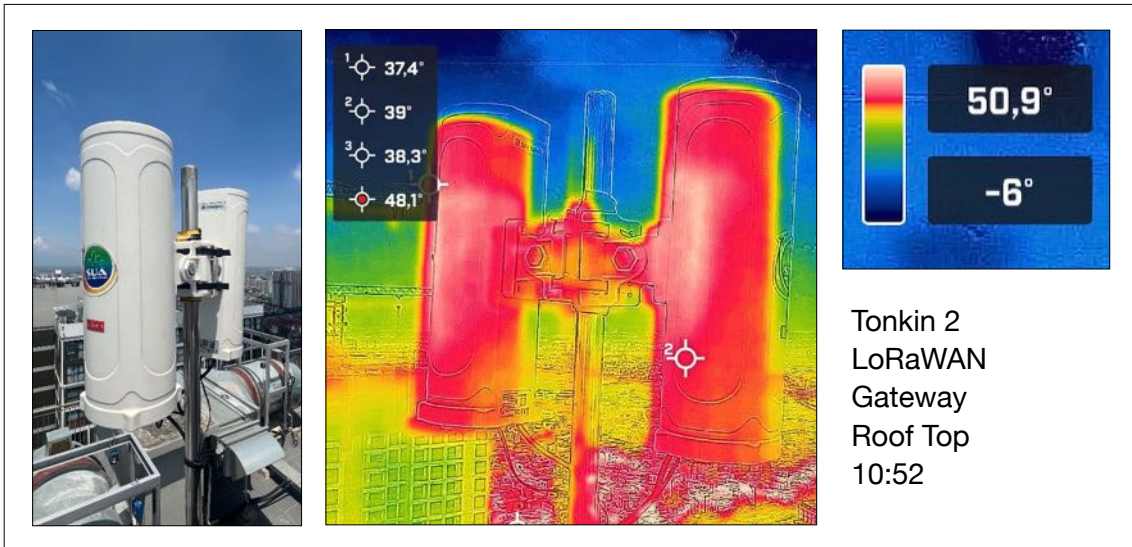
In addition to the material included in the Appendices, further information and documentation can be accessed via the project webpage: www.smarturbanareas.de

Appendix A.1: Thermal Imaging and Facade Orientation

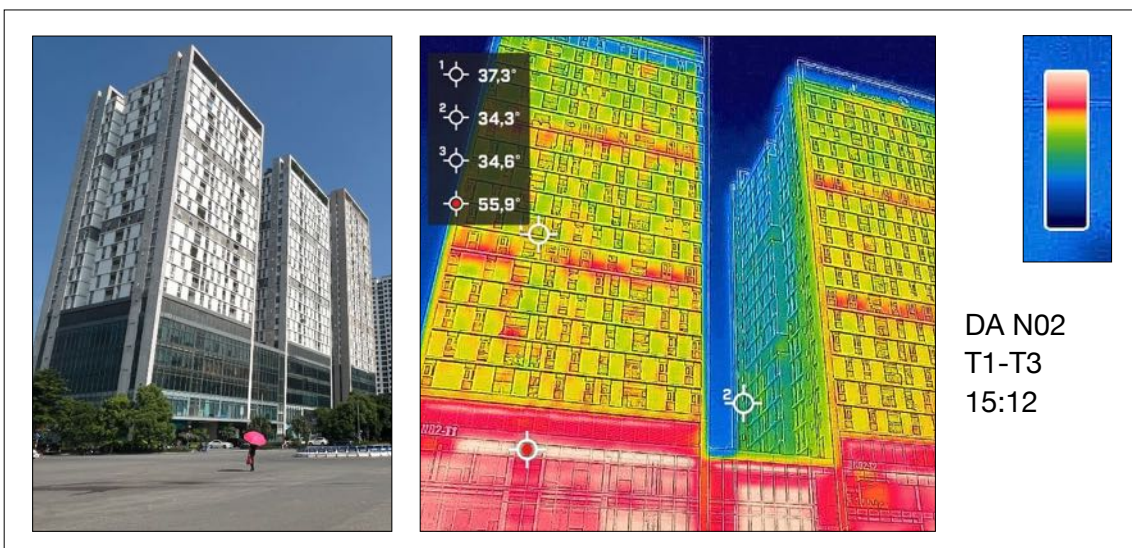
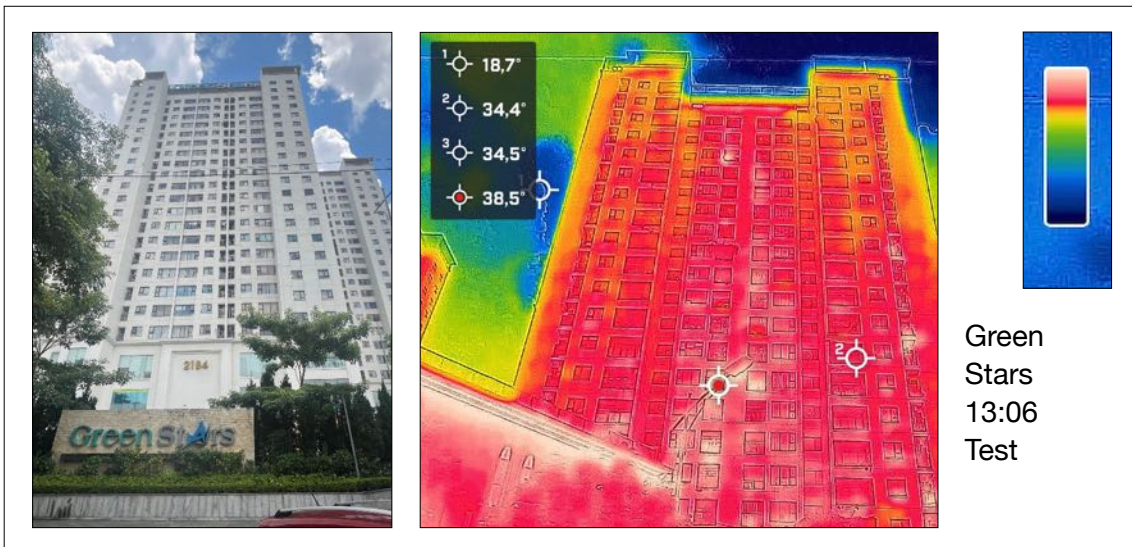
The thermal images down below were gathered on date 07.08.2024:

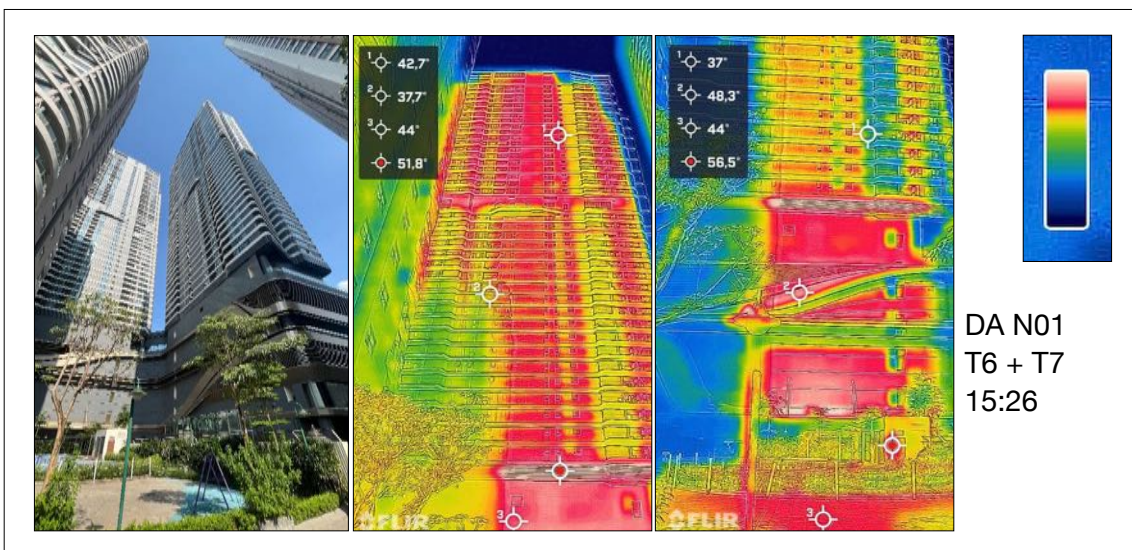
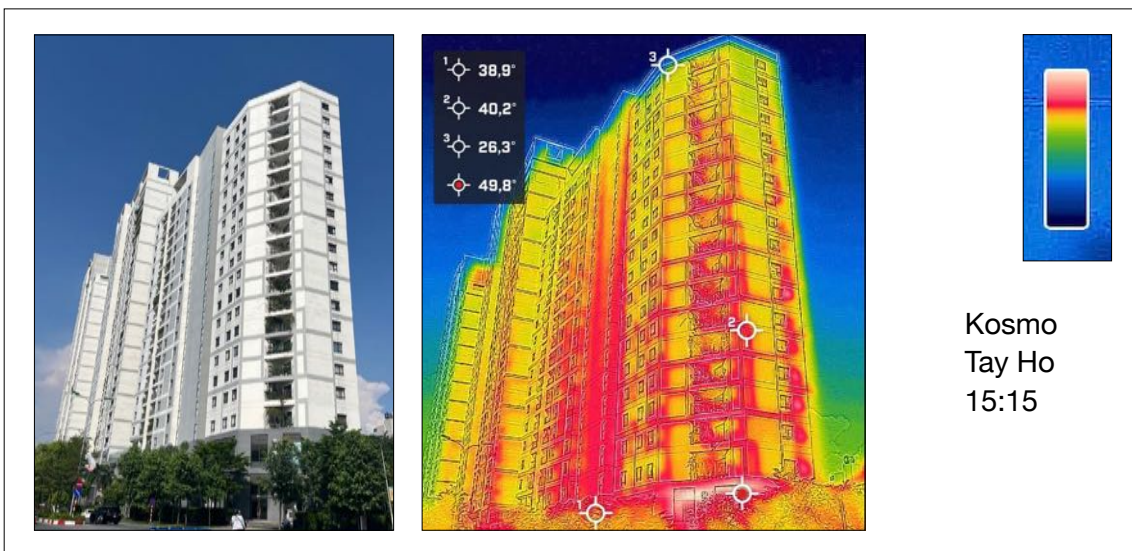
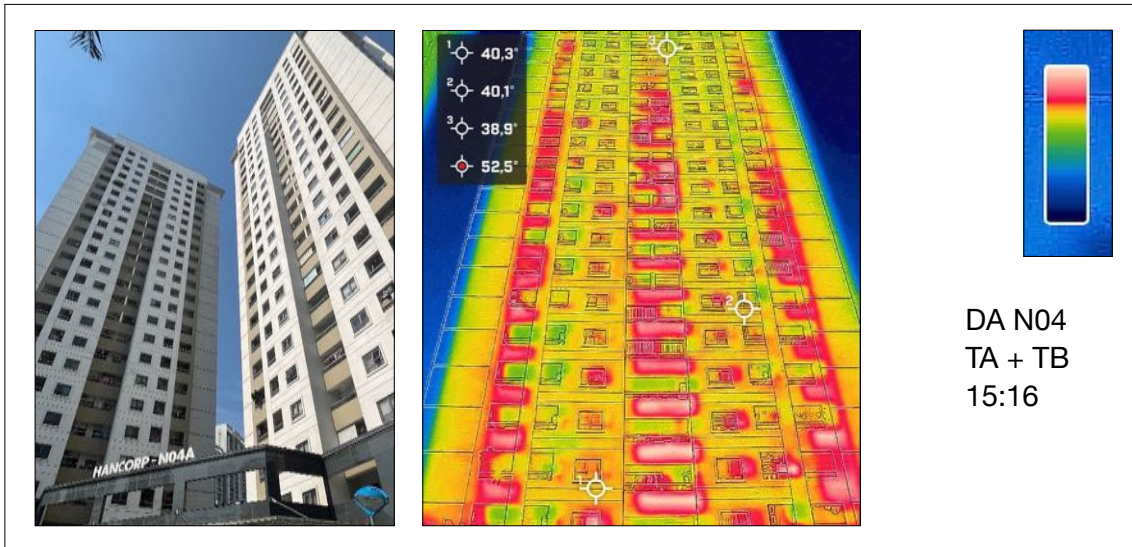


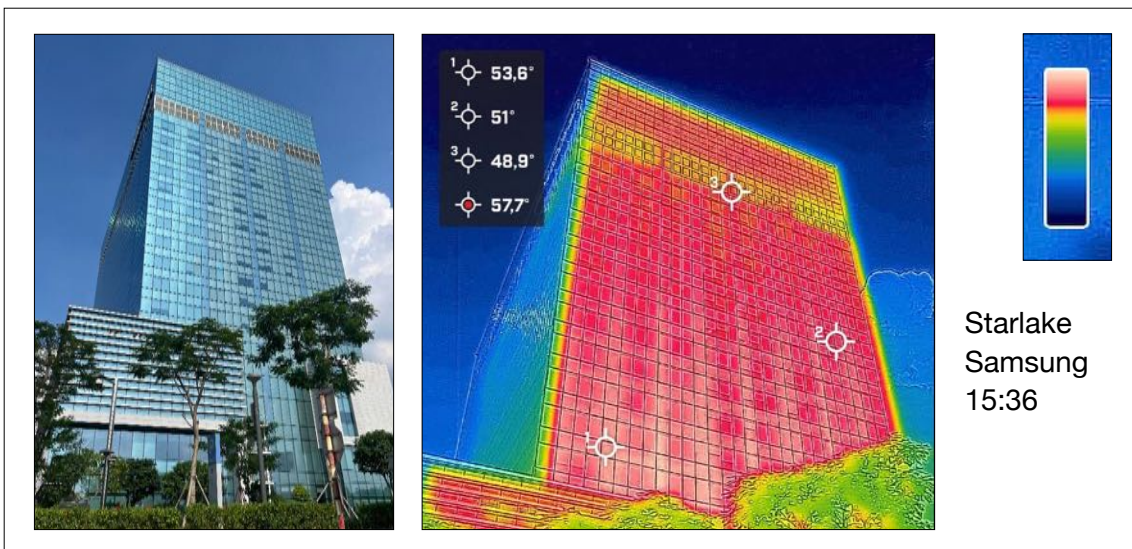
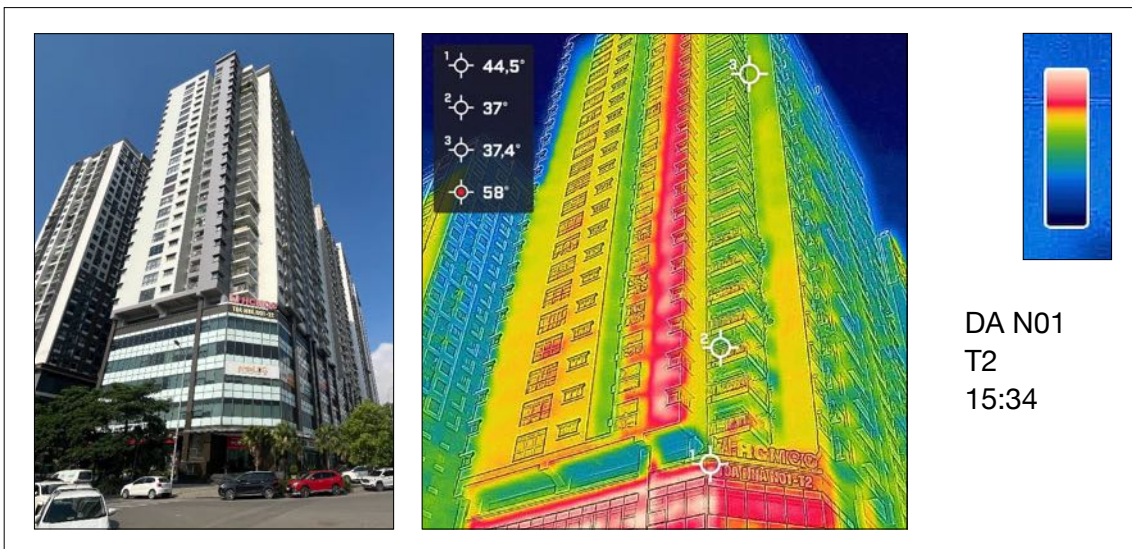
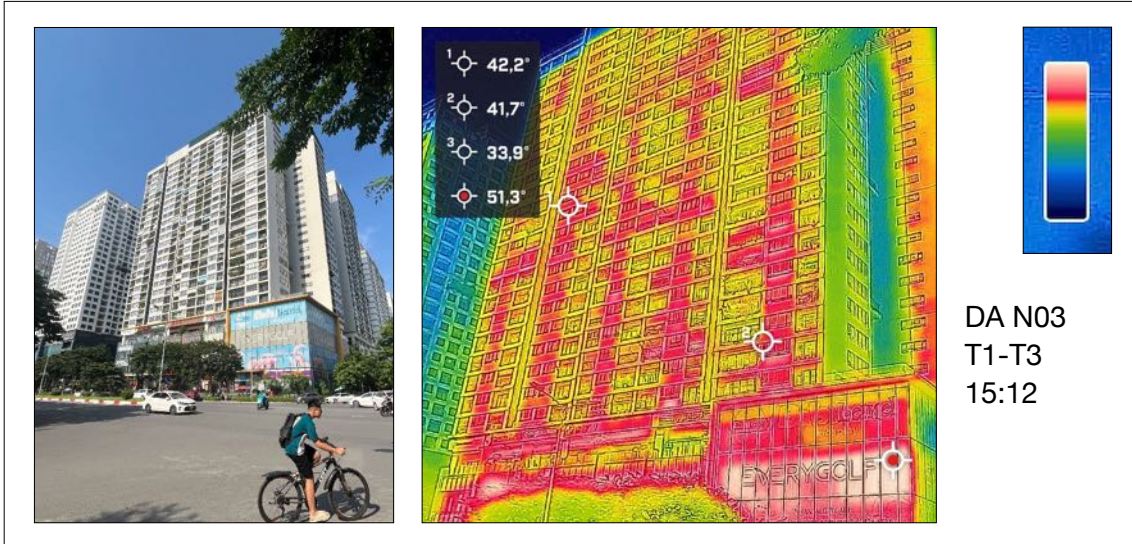


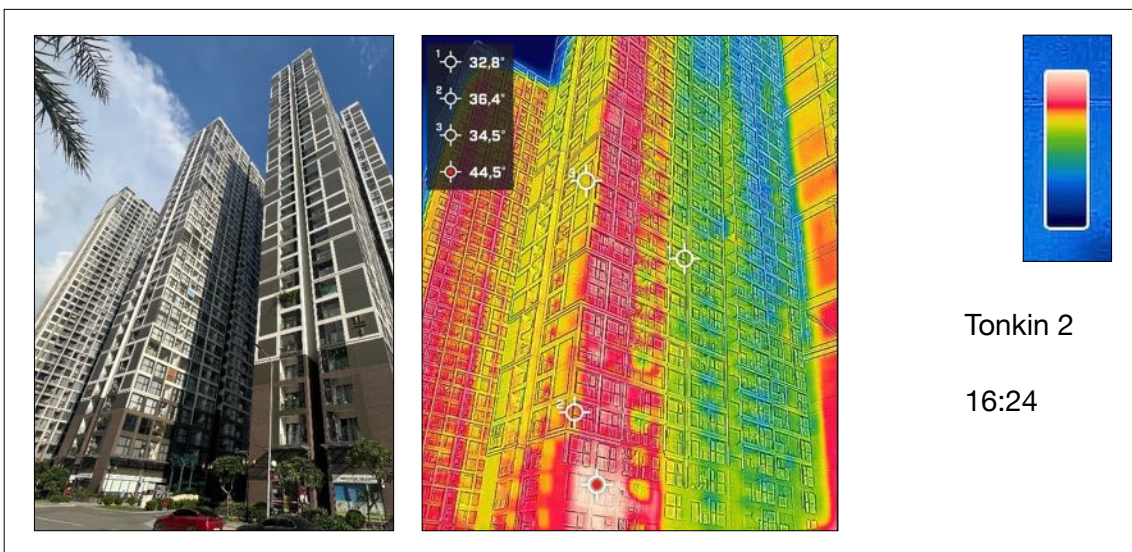
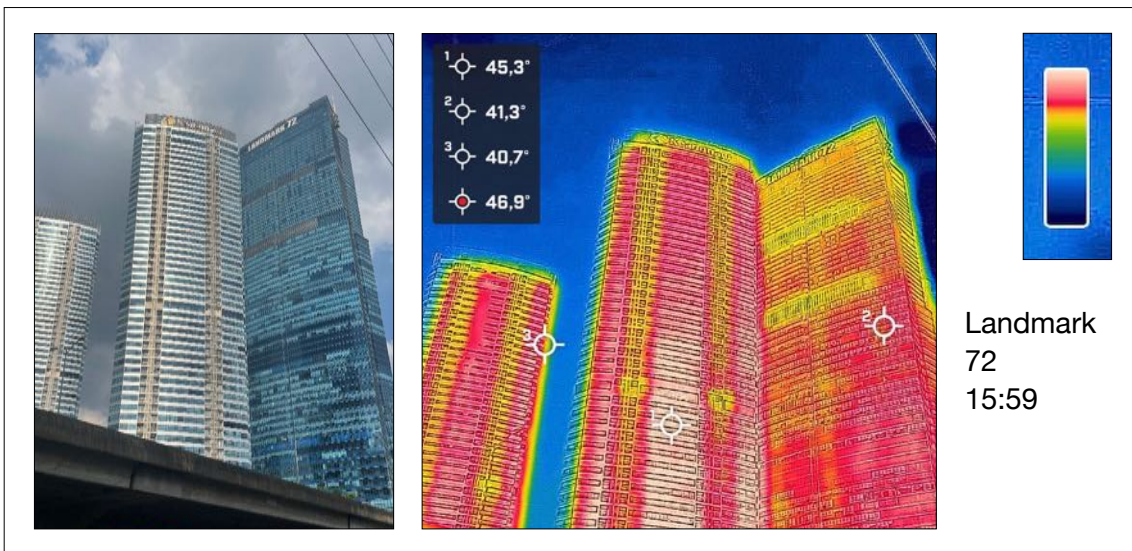
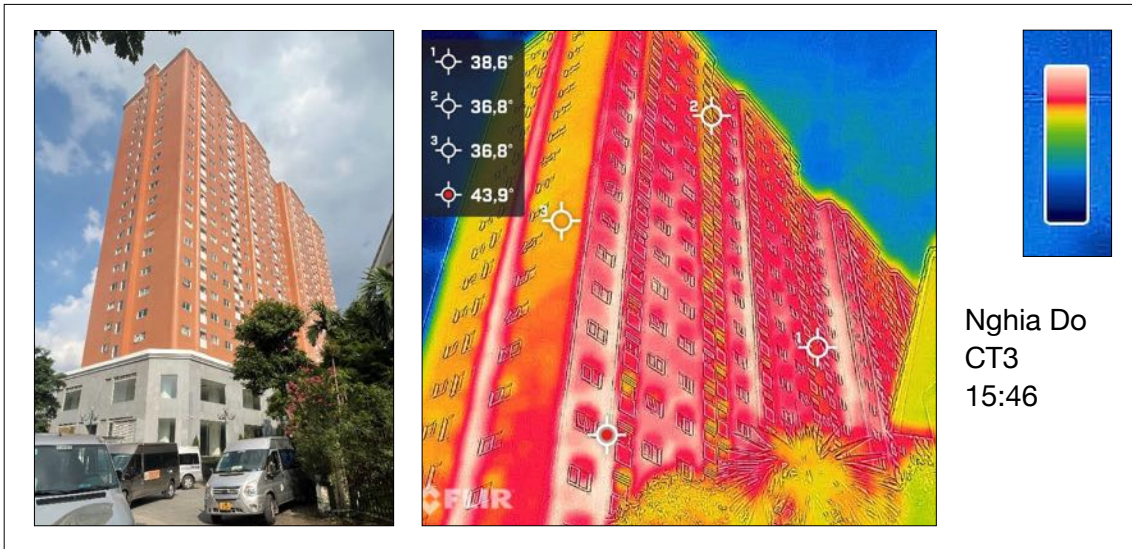


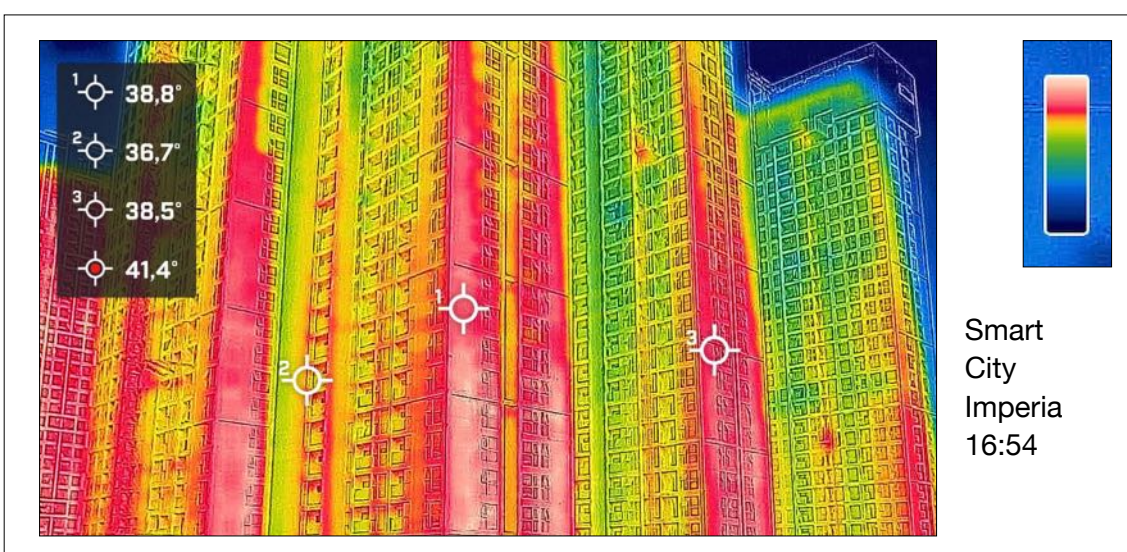
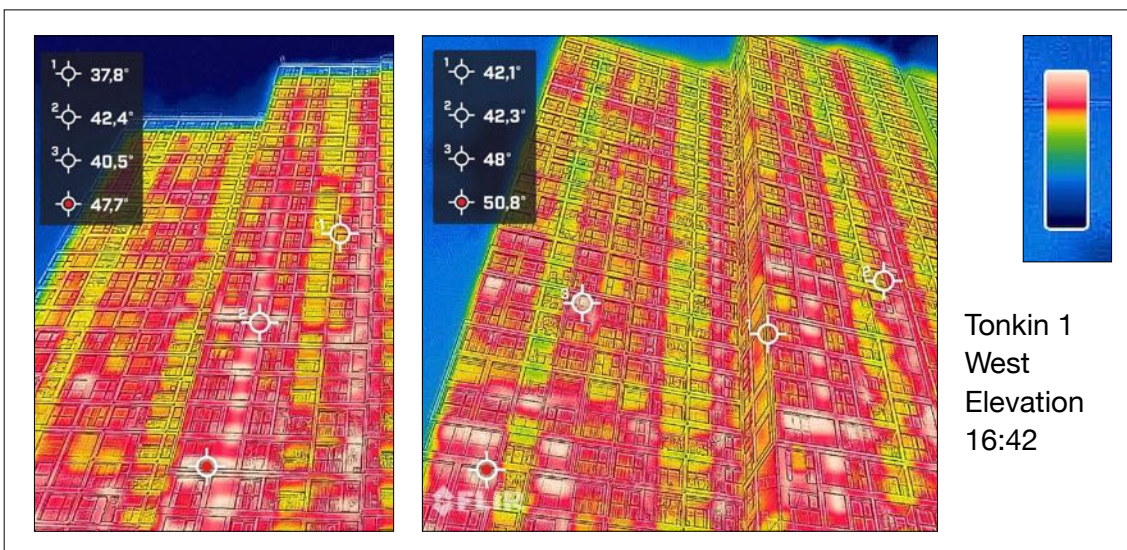
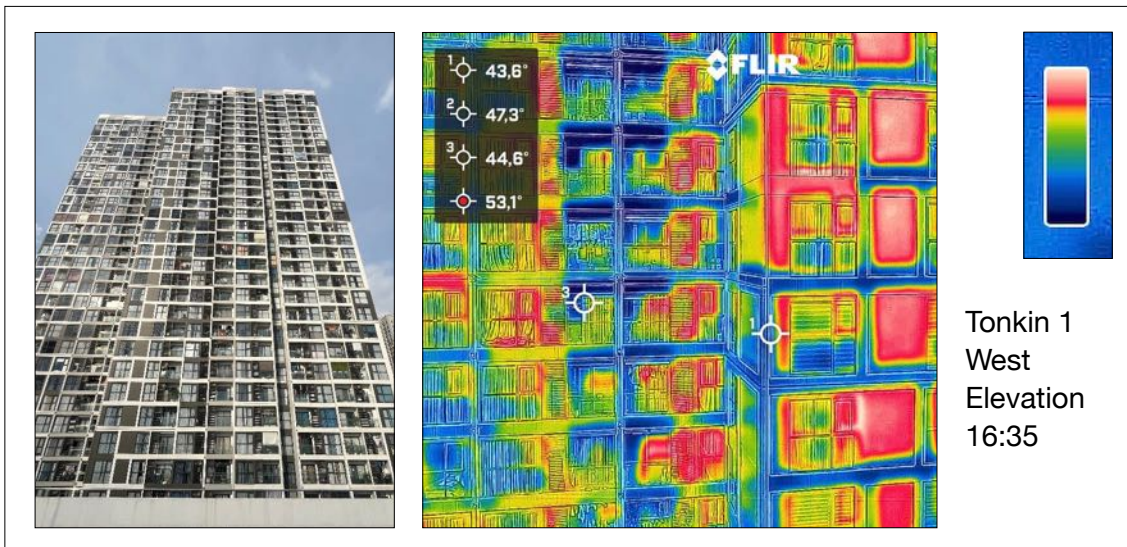
The following images are taken in the afternoon on date 07.08.2024; all elevations facing West.

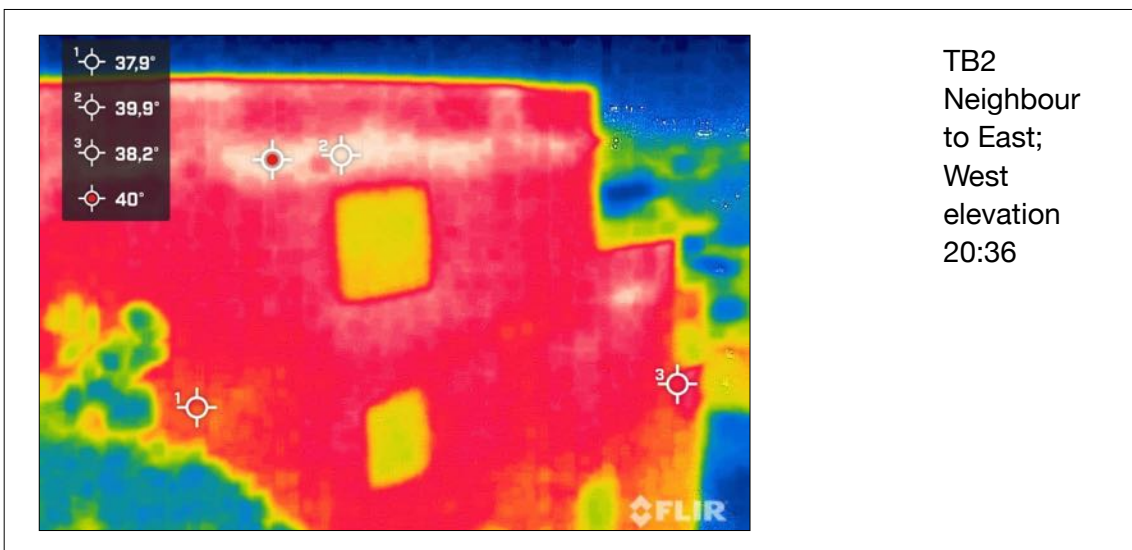
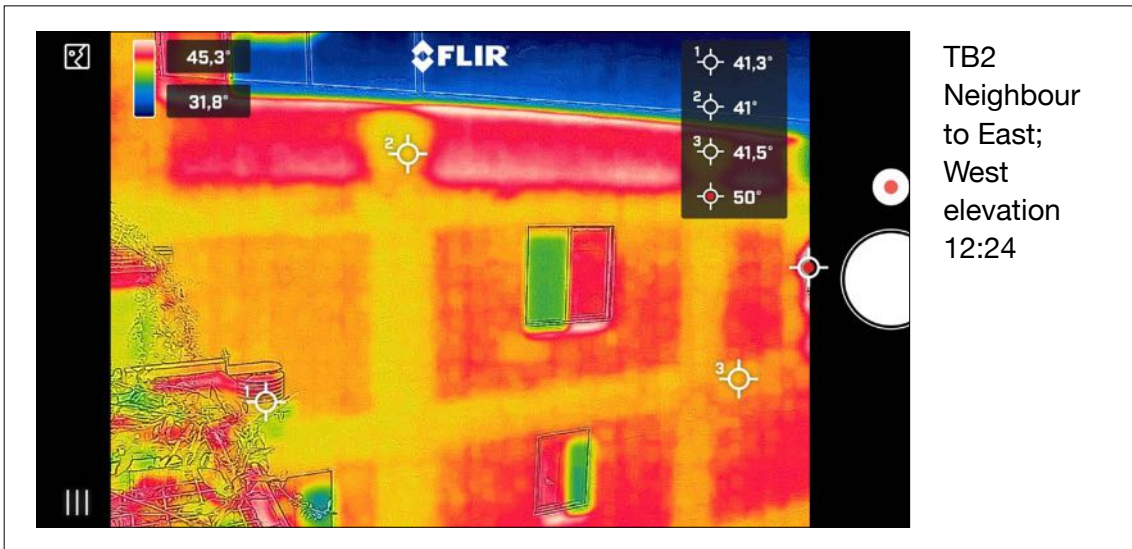
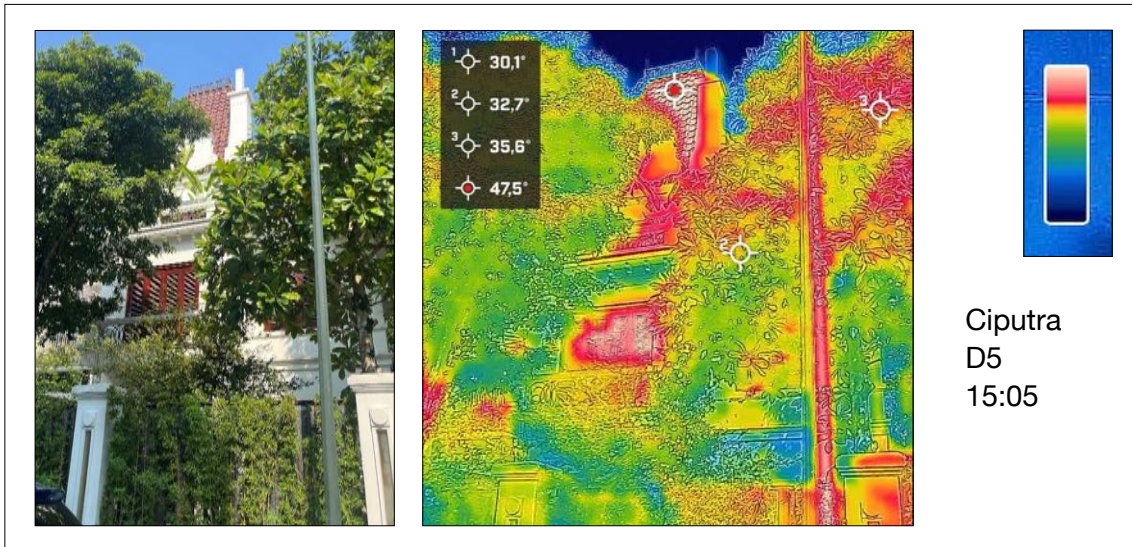




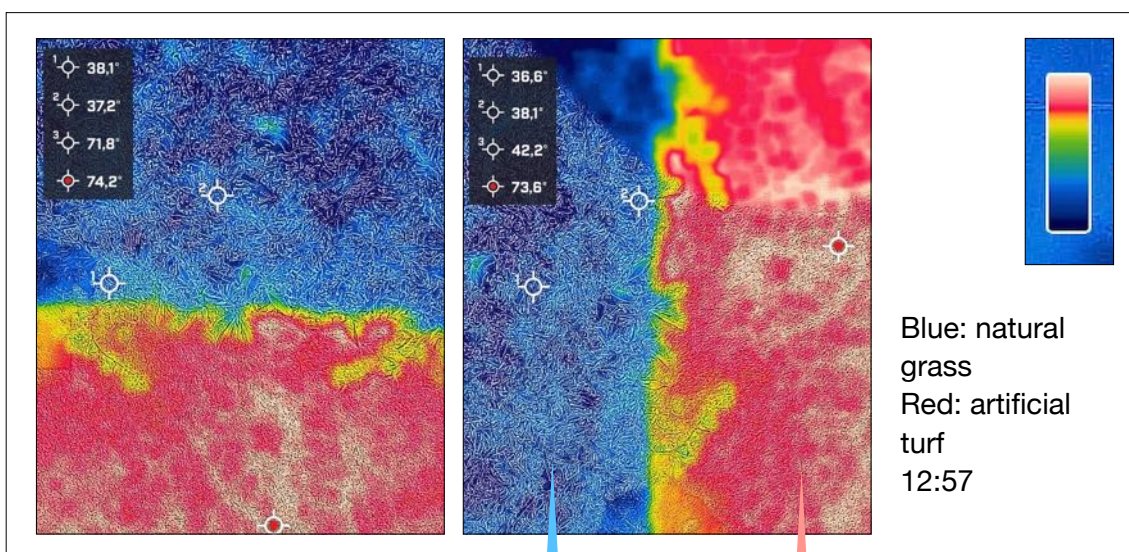
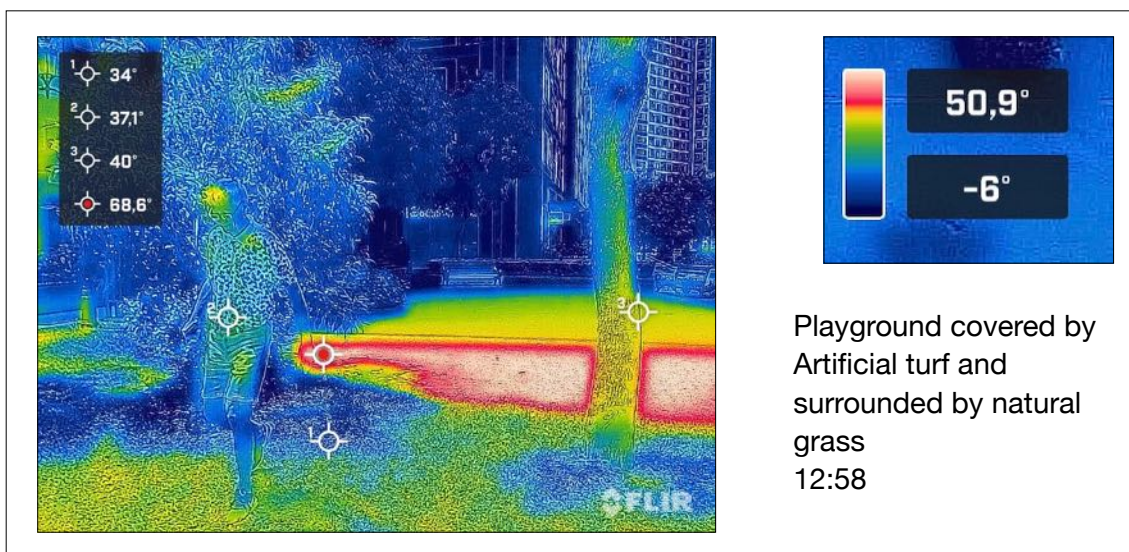








The following thermal images taken at playground of VSC on date 02.05.2025 represent natural grass compared to artificial turf:



Natural Grass

Artificial Turf

Appendix A.2: Wall Assembly Material Breakdowns for the Building Envelope of T2 (per m² of Wall Area)

The table down below provides information based on National Technical Regulation on Energy Efficiency Buildings QCVN 09:2017/BXD by the Ministry of Construction (MoC) besides data taken by the author in correspondence accordingly. The construction materials B1, B2 and AAC are available in Vietnam while the advanced Poroton (Planziegel T8-36,5)³⁹ is a material based on clay, currently available in Europe, and should provide information about technological possibilities working with traditional clay.

Table A3.1: Comparative Wall Material Parameters for one Square Meter

Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer	Poroton Single Layer
Material & Dimensions					T8-36,5
Dimension	mm	210/100/55 (57)	210/100/55 (57)	200/200/600	248/365/249
Weight	Kg	1.3-1.5	1.3-1.5	15.6	13,5
Material	-	Clay	Clay	Autoclaved Aereted Concrete	Clay
Thermal conductivity λ	W/mK	0.7	0.7	0.16	0.08
U-Value	W/m ² K	2.65	2.92	0.77	
R-Value	m ² K/W	0.3769	0.34	1.31	
One Square Meter (m²)					
Bricks	pcs	56,50	113	9	16
Brick weight	Kg/m ²	73,45	146,90	140,40	216,00
Air gap thickness	mm	-	20-30	-	-
Mortar weight	Kg/m ²	51,79	120,35	1,8	4,6
Plaster weight	Kg/m ²	72,00	72,00	9,60	16,00

³⁹ www.wienerberger.de/produkte/wand/ziegel/poroton-planziegel-t8-36,5.html (5.6.2024)

Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer	Poroton Single Layer
Wall thickness (incl. plaster)	cm	15	25	20.6	36.5
Wall type location	-	Interior	Exterior	Exterior	Exterior
Weight	Kg/m2	197,24	339,25	151,80	236,60
Construction time					
Laying time	min	60	200	30	40
Plaster time (2 layer) incl. curing	min	120	300	30	100
Total	min	180	500	60	140

Calculations:

Cement render (plaster) for B1 and B2:

Outside (30 mm): Volume = $0.030 \text{ m}^3 \rightarrow \text{Mass} = 0.030 \text{ m}^3 \times 1600 \text{ kg/m}^3 = 48.0 \text{ kg/m}^2$

Inside (15 mm): Volume = $0.015 \text{ m}^3 \rightarrow \text{Mass} = 0.015 \text{ m}^3 \times 1600 \text{ kg/m}^3 = 24.0 \text{ kg/m}^2$

Total render mass: 72.0 kg/m^2

Brickwork (core layer 100 mm) B1:

Brick unit size: $210 \times 100 \times 57 \text{ mm}$

Geometric volume per brick = $0.210 \times 0.100 \times 0.057 = 0.001197 \text{ m}^3$

Brick count: 56.5 bricks/m^2 (with 20 mm joints)

Total brick volume: $56.5 \times 0.001197 = 0.06763 \text{ m}^3/\text{m}^2$

Average mass per brick: $1.3 \text{ kg} \rightarrow \text{Brick mass: } 56.5 \times 1.3 = 73.45 \text{ kg/m}^2$

Mortar (bed + head joints) B1:

Gross layer volume at 100 mm: $1.00 \text{ m}^2 \times 0.10 \text{ m} = 0.10 \text{ m}^3$

Mortar volume: $0.10 - 0.06763 = 0.03237 \text{ m}^3/\text{m}^2$

Mortar mass: $\rho_{\text{mortar}} = 1,600 \text{ kg/m}^3$

mass = $0.03237 \times 1,600 = 51.79 \text{ kg/m}^2$

Brickwork (core layer 200 mm) B2

Brick unit size: $210 \times 100 \times 57 \text{ mm (x2)}$
Geometric volume per brick = $0.210 \times 0.200 \times 0.057 = 0.002394 \text{ m}^3$
Brick count: $113 \text{ bricks/m}^2 \text{ (with 20 mm joints)}$
Total brick volume: $113 \times 0.002394 = 0.270522 \text{ m}^3/\text{m}^2$
Average mass per brick: $1.3 \text{ kg} \rightarrow \text{Brick mass: } 113 \times 1.3 = 146.9 \text{ kg/m}^2$

Mortar (bed + head joints) B2:

Gross layer volume at 200 mm: $1.00 \text{ m}^2 \times 0.20 \text{ m} = 0.20 \text{ m}^3$
Mortar volume: $0.270522 - 0.20 = 0.07522 \text{ m}^3/\text{m}^2$
Mortar mass: $\rho_{\text{mortar}} = 1,600 \text{ kg/m}^3$
 $\text{mass} = 0.07522 \times 1,600 = 120.35 \text{ kg/m}^2$

Render (plaster) for AAC:

Outside/Inside (3 mm): $\text{Volume} = 0.003 \text{ m}^3 \rightarrow \text{Mass} = 0.030 \text{ m}^3 \times 1.600 \text{ kg/m}^3 =$
 $4.8 \text{ kg/m}^2 \times 2$
Total render mass: 9.6 kg/m^2

Block work (core layer 200 mm) AAC

Block unit size: $200 \times 200 \times 600 \text{ mm (x2)}$
Geometric volume per brick = $0.20 \times 0.20 \times 0.6 = 0.024 \text{ m}^3$
Block count: $9 \text{ blocks/m}^2 \text{ (with 3 mm joints)}$
Total block volume: $9 \times 0.024 = 0.216 \text{ m}^3/\text{m}^2$
Average mass per block: $15.6 \text{ kg} \rightarrow \text{Block mass: } 9 \times 15.6 = 140.4 \text{ kg/m}^2$

Adhesive powder (bed + head joints) AAC:

Horizontal joint volume: $1.0 \times 0.2 \times 0.003 = 0.0006$
Horizontal joint line: $0.0006 \times 5 = 0.003 \text{ m}^3$
Vertical joint volume: $0.2 \times 0.2 \times 0.003 = 0.00012$
Vertical joint line: $0.00012 \times 5 = 0.0006$
Joints together: $0.003 + 0.0006 = 0.0036$
Mortar mass: $\rho_{\text{mortar}} = 1.500 \text{ kg/m}^3$
 $\text{mass} = 0.0036 \times 1.500 = 5.4 \text{ kg/m}^2$

Render (plaster) for Poroton:

Outside/Inside (10 mm): $\text{Volume} = 0.010 \text{ m}^3 \rightarrow \text{Mass} = 0.010 \text{ m}^3 \times 1.600 \text{ kg/m}^3 =$
 $16 \text{ kg/m}^2 \times 2$
Total render mass: 16 kg/m^2

Block work (core layer 365 mm) Poroton:

Brick unit size:	248 × 365 × 249
Geometric volume per brick =	$0.248 \times 0.365 \times 0.249 = 0.0225 \text{ m}^3$
Block count:	16 blocks/m ² (with 3 mm joints)
Total block volume:	$16 \times 0.0225 = 0.36 \text{ m}^3/\text{m}^2$
Average mass per block:	13.5 kg → Block mass: $16 \times 13.5 = 216 \text{ kg/m}^2$

Adhesive powder (bed + head joints) Poroton:

Horizontal joint volume:	$1.0 \times 0.2 \times 0.003 = 0.0006$
Horizontal joint line:	$0.0006 \times 4 = 0.0024 \text{ m}^3$
Vertical joint volume:	$0.2 \times 0.2 \times 0.003 = 0.00012$
Vertical joint line:	$0.00012 \times 4 = 0.00048$
Joints together:	$0.0024 + 0.00048 = 0.00288$
Mortar mass:	$\rho_{\text{mortar}} = 1.600 \text{ kg/m}^3$
	$\text{mass} = 0.00288 \times 1.600 = 4.6 \text{ kg/m}^2$

Table A3.2: Cost Estimations for Materials, Construction Time, CO2 Emissions on one Square Meter

Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer	Poroton Single Layer
Cost estimation*					
Brick	VND	67.800	135.600	270.000	-
Plaster	VND	130.000	130.000	100.000	-
Mortar/Adhesive	VND	120.000	240.000	80.000	-
					-
Laying cost	VND	300.000	1.000.000	150.000	-
Plaster time	VND	499.920	1.249.800	124.980	
Total cost per m²	VND	1.117.720	2.755.400	724.980	-
Cost	USD				-
	* prices are vague and depending on city, site, contractor and product brand. Average prices are used:				
	_AAC: 30.000 VND per block				
	_Brick: 1.200 VND per brick				
	_Plaster: 65.000 VND per m ² / layer				
	Mortar cement: 120.000 VND per m ²				

Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer	Poroton Single Layer
	_Adhesive: 80.000 VND per m ²				
	_Labor cost: 300.000 VND per hour				
	_Plaster cost: 250.000 VND per hour				
Life Cycle Assessment (LCA)**					
A1-A3	kg CO ₂ e/m ²	26,988	44,616	29,232	49,600
A4	kg CO ₂ e/m ²	0,888	1,527	0,683	1,065
Total LCA	kg CO₂e/m²	28	46	30	51

** calculations based on ICE v.2.0 from Bath University⁴⁰ (2011) while the ICE v.4 (12/2024) both equational and advanced version malfunction. The LCA is simplified and does not focus on 50 years commission or end of life calculations due not viable and verified data:

A1-A3 (manufacturing (cradle-to-gate):

Fired clay brick: 0.24 kg CO₂e/kg

AAC block: 0.20 kg CO₂e/kg

Poroton block: 0.22 kg CO₂e/kg

Gypsum based (plaster): 0.12 kg CO₂e/kg (AAC)

Cement (mortar/plaster): 0.13 kg CO₂e/kg (brick/Poroton)

A4 (transport):

heavy truck, 5 axle 0.09 kg CO₂e/ton-km

Calculation example for traditional brick A1-A3:

Weight brick

73.45 kg x 0.24 CO₂e/kg + cement plaster 72 kg x 0.13 → 26.988 kg CO₂e/m²

Calculation example for brick wall A4 and radius of 50 km:

Mass/Weight wall


197.24 Kg/m² x 50 km x 0.09 CO₂e/tKm = 887 Kg CO₂e / 1000 tKm =

0.88758 Kg CO₂e/m²

The following table A3.2 provides information about the building envelope material and construction time in conclusion with the amount of payloads and CO₂ emission.

⁴⁰ <https://greenbuildingencyclopaedia.uk/wp-content/uploads/2014/07/Full-BSRIA-ICE-guide.pdf> (3.5.2025)

Table A3.2: Scaled Building Envelope Materials on T2 BCR (9.796 m²)

Parameters	Unit	SL Brick (B1)	DL Brick (B2)	SL AAC
Construction Material				
Bricks	pcs	553.474	1.106.948	88.164
Brick weight	Kg	719.516	1.439.032	1.375.358
Mortar weight	Kg	507.335	1.178.949	17.633
Plaster weight	Kg	705.312	705.312	94.042
Weight	Kg	1.932.163	3.323.293	1.487.033
Construction time (min)				
Laying time	min	587.760	1.959.200	293.880
Plaster time (2 layer) incl. curing	min	1.175.520	2.938.800	293.880
Sum	min	1.763.280	4.898.000	587.760
	hrs	29.388	81.633	9.796
	d	1.225	3.401	408
	w	175	486	58
	Y	3	9	1
Payloads for Masonry*				
				
Trucks brick	pl	29	57	47
Trucks mortar	pl	437	1.016	15
Trucks plaster	pl	608	608	81
Total	pl	1.074	1.682	144
CO2 Emission				
brick	kg CO ₂ e/m ²	3.238	6.476	6.189

Parameters	Unit	SL Brick (B1)	DL Brick (B2)	SL AAC
mortar	kg CO ₂ e/m ²	3.298	7.663	115
plaster	kg CO ₂ e/m ²	4.585	4.585	611
Total	kg CO ₂ e/m ²	11.120	18.723	6.915
Cost estimation				
Bricks	VND			
Mortar	VND			
Plaster	VND			
Trucks	VND			
Total	VND			
Total	USD			

* Net vehicle weight of 5 axle truck (15 ton (t))
 Gross vehicle weight (GVW) by regulation (max. 44t)
 Payload calculation: 44.000 Kg - 15.000 Kg = 29.000 Kg

Calculation example for bricks (1.5 Kg/pc)

$29.000 \text{ Kg} / 1.5 \text{ Kg} = 19.333 \text{ pcs/truck}$

Calculation example for AAC (15.6 Kg/pc)

$29.000 \text{ Kg} / 15.6 \text{ Kg} = 1.859 \text{ pcs/truck}$

Calculation example for mortar and plaster (25 Kg/bag)

$29.000 \text{ Kg} / 25 \text{ Kg} = 1.160 \text{ bags/truck}$


Table A3.3 provides information from table A3.2 scaled up to the dimensions of Vinhomes Smart City Hanoi (VSC) high rise buildings based on the multiplied building plans, similar heights and overall similar layouts. Even these numbers represent a bigger picture of the overall data, inaccuracies and a deviation of about 5-10% is realistic. This table underpins a tendency for further investigations and considerations.

Within the VSC similar types and shapes of Tonkin 2 (T2) are to be found and partly

under construction (2025):

- 26x `T2` types of building
 - 15x `T2` doubling types = 30 `T2`
 - 2x L-shape tower = 2x T2 tower
 - 2x Circular shape tower = 2x T2 tower
- ➔ **60 T2 similar towers**


Table A3.3: Scaled Building Envelope adapted on VSC Hanoi


Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer
Construction Material				
Bricks	pcs	33.208.440	66.416.880	5.289.840
Brick weight	Kg	43.170.972	86.341.944	82.521.504
Mortar weight	Kg	30.440.090	70.736.916	1.057.968
Plaster weight	Kg	42.318.720	42.318.720	5.642.496
Weight	Kg	115.929.782	199.397.580	89.221.968
Construction time				
Laying time	min	35.265.600	117.552.000	17.632.800
Plaster time (2 layer) incl. curing	min	70.531.200	176.328.000	17.632.800
Sum	min	105.796.800	293.880.000	35.265.600
	hrs	1.763.280	4.898.000	587.760
	d	73.470	204.083	24.490
	w	10.496	29.155	3.499
	y	202	561	67
Payloads				
				
Trucks brick	pl	1.718	3.435	2.846

Parameters	Unit	Brick (B1) Single Layer	Brick (B2) Double Layer	AAC Single Layer
Trucks mortar	pl	26.241	60.980	912
Trucks plaster	pl	36.482	36.482	4.864
Total	pl	64.441	100.897	8.622
CO2 Emissions				
brick	kg CO ₂ e/m ²	194.269	388.539	371.347
mortar	kg CO ₂ e/m ²	197.861	459.790	6.877
plaster	kg CO ₂ e/m ²	275.072	275.072	36.676
Total	kg CO ₂ e/m ²	667.202	1.123.400	414.900

Table A3.4: Reinforced Concrete Slab Calculations T2

Parameters	Plan area (m ²)	Length (lm)	Floors (fl)	Volume (m ³)
General Notes				
	Standard floor height 3.400 mm = 3.40 m			38 floors
	1st floor height 5.500 mm = 5.50 m			1 floor
	Standard slab thickness 160 mm = 0.16 m			all
All floor slabs are equipped with exterior boundary beams and interior beams within the frame work construction of columns in shape of rectangular walls				
Construction				
Reinforced concrete slab (160 mm) 196.88 m ³	1.230,520		39	7.678,44
Beams exterior (290 x 300 mm) 22,25 m ³	0,087	255,70	38	845,34
Beams interior (290 x 200 mm) 12,16 m ³	0,058	209,59	38	461,94

Parameters	Plan area (m ²)	Length (lm)	Floors (fl)	Volume (m ³)
Core walls 1 floor (height = 5.340 mm) w/ slab	8,200	5,34	1	43,79
Core walls other floors (height = 3.240 mm) w/ slab	8,200	3,24	38	1.009,58
Columns* 1 floor (height = 5.340 mm) w/ slab	50,766	5,34	1	271,09
Columns 2-10 floors (height = 3.240 mm) w/ slab	50,551	3,24	9	1.474,07
Columns 11-38 floors (height = 3.240 mm) w/ slab	49,859	3,24	28	4.523,21
Total concrete (reinforced)				16.307,46
Weight**				
Total in Kg/m ³				39.137.896
Total in metric ton				39.138
Concrete Mixer***				
Total	pl			3.914
CO2 Emissions****				
Concrete A1-A3	kg CO ₂ e/m ³			4.070
Transport A4	kg CO ₂ e/m ³			20.352
Total	kg CO₂e/m³			24.422
Concrete Formers*****	Reduction based on 4974 spheres in slabs, see down below:			
Reinforced concrete slab (210 mm) 177.01 m ³	1.230,520		39	6.903,36
Core walls 1 floor (height = 5.290 mm) w/ slab	8,200	5,29	1	43,38

Parameters	Plan area (m ²)	Length (lm)	Floors (fl)	Volume (m ³)
Core walls other floors (height = 3.00 mm) w/ slab	8,200	3,00	38	934,80
Columns* 1 floor (height = 5.290 mm) w/ slab	50,766	5,29	1	268,55
Columns 2-10 floors (height = 3.00 mm) w/ slab	50,551	3,00	9	1.364,88
Columns 11-38 floors (height = 3.00 mm) w/ slab	49,859	3,00	28	4.188,16
Total concrete (reinforced)				13.703,12
Weight			(Saving) Diff m ³	2.604,33
			Total in Kg/m ³	32.887.493
Unidome XS60 350 x 350 mm grid (slab thickness 210 mm)			(Saving) Diff Kg/m ³	6.250.404
			Total in metric ton	32.887
Concrete Mixer				
Total	pl			3.289
(Savings) Difference	pl			625
CO2 Emissions				
Concrete A1-A3	kg CO ₂ e/m ²			3.420
Transport A4	kg CO ₂ e/m ²			17.101
Total	kg CO ₂ e/m ²			20.522
(Saving)Difference	kg CO ₂ e/m ²			3.900

* There are in general 48 columns per floor plus additional 2 columns that close the boundary of the emergency stair cases. These two wall were included and excluded from the core. Therefore the calculation is based on 50 columns.

** Weight calculation is based on 2.400 kg/m³ per cubic meter concrete.

*** Calculation based Gross vehicle weight (GVW) for a 24 ton 3 axle

concrete mixer truck with a maximum payload of 10 cubic meter (cbm) concrete.

**** calculations based on ICE v.2.0 from Bath University, typical concrete factor
 A1-A3 = 0.104 kg CO₂e/kg
 = 2.400 kg/m³ x 0.104 kg CO₂e/kg = 249.6 = 250 kg CO₂e/m³

Calculations based on Greenhouse Gas Report⁴¹

A4 (50km) = 24 ton x 50km x 0.104 kg CO₂e/kg / 10 m³ = 12.48 kg CO₂e/m³

***** Calculation for resource saving benefits using 4974 UniDome concrete former XS60 (0.016366 m³/ea = 81.40 m³ total) stands equivalent to a slab thickness of 210 mm, due the concrete former's height of 90 mm plus concrete cover to both sides of 60 mm.

Original slab with beams: 196.88 m³ + 22.25 m³ + 12.16 m³ = 231,29 m³

Unidom slab w/ beams: 1,230.52 m³ x 0.21 m - 81.4 m³ = 177.01 m³
 = 231.29 m³ - 177.01 m³ = 54.28 m³ / floor
 = 54.28 m³ x 39 floors = 2,116.92 m³
 = 7,978.44 m³ - 2,116.92 m³ = 5,861.52 m³
 = 27.2% savings

or

(slabs) 7.678,44 + (beam ex) 845,34 + (beam in)
 461,94 = 8.985,68 - 6.903,36 m³ = 2.082,32 m³
 reduction in volume = 22%

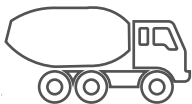
It is really depending from which direction resource savings are measured and calculated. An average of 25% can be set.

Table A3.5 interpolates the numbers from previous table and multiply those by factor 60 that is equivalent to the previously mentioned 60 high rise buildings in the VSC.

Tab. A3.5: Reinforced Concrete Consumption and Potentials at VSC



Parameters	Unit	Volume
Material		
Currently	Metric (ton)	2.348.274
Reduction (saving)	Metric (ton)	375.024
Total	Metric (ton)	1.973.250
CO2 emission		

⁴¹ <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2024> (09.09.2025)

Parameters	Unit		Volume
Currently	kg CO ₂ e/m ³		1.465.323
Reduction (saving)	kg CO₂e/m³		234.015
Total	kg CO ₂ e/m ³		1.231.308
Concrete Mixer			
Currently	pl		234.827
Reduction (saving)	pl		37.502
Total	pl		197.325

Tab. A3.6: Technical Building Equipment

External loads	Apt (qty)	AC units	AC type			AC brackets	Weight (kg)
2-38 (37 floors)			S 12-15 BTU (30 kg)	M 18-24 BTU (50 kg)	L 36-60 BTU 80kg	6 kg (pair/unit)	
East facade (E_f)							
Studio	74	74	74			444	2.664
1-bed Apartment	74	148	74	74		888	6.808
2-bed Apartment	148	444	592	148		2.664	27.824
3-bed Apartment	37	111	111			666	3.996
Sub Total	333	777	25.530	11.100	0	4.662	41.292
South facade (S_f)							
Studio	0	0	0	0	0	0	0
1-bed Apartment	0	0	0	0	0	0	0
2-bed Apartment	74	0	0	0	0	0	0
3-bed Apartment	0	0	0	0	0	0	0
Sub Total	74	0	0	0	0	0	0
West facade (W_f)							
Studio	37	37	37			222	1.332
1-bed Apartment	37	74	37	37		444	3.404
2-bed Apartment	148	444	592	148		2.664	27.824

External loads	Apt (qty)	AC units	AC type			AC brackets	Weight (kg)
			S 12-15 BTU (30 kg)	M 18-24 BTU (50 kg)	L 36-60 BTU 80kg		
2-38 (37 floors)						6 kg (pair/unit)	
Airbus A 380							560.000
Airbus A 330							242.000

* The technical documentation received by the author is incomplete, omitting various technical items of building equipment (such as pumps, related foundational elements, and technical apparatus beyond metal piping and ducts) that are visibly on site. Due to this inconsistency between documented and observed data, and in comparison with measured structural information, it is estimated that an additional 5 to 10 percent of the total calculated weight should be added as general external loads impacting the structural framework of the entire building. This magnitude of unaccounted load makes a comparative analogy with an Airbus A 380 a realistic example.

By replacing such loads through horizontal vegetation for roof greening reduces the overall loads by nearly 50 percent that also affects the consumption of concrete, steel rebars, sand and water, materials that are required for construction. Than in contrast a comparison with a much smaller aircraft such as an Airbus A 330 is reasonable.

**MTOW = Maximum Tons Of Weight

Appendix A.6: Filtration Capacity Calculations and Electricity Consumption

Down below in the table all data measured from February till September 2025 are listed including average values.

Date (d)	Time (ICT-Hanoi)	Filtrate (m3)	Days (btwn.)	Avg (m ³ /d)	Avg (m ³ /m)	Electricity (kW/h/d)	Avg. Elt. (kW/h/m)
21/02/2025	18:38:47					0,0	
26/02/2025	12:11:54	2					
27/02/2025	14:59:36					41,3	
08/03/2025	15:37:41	3	11	0,091			
11/03/2025	17:04:05	3	3	0,000	0,045		1.142,7
21/03/2025	10:06:20					821,6	
05/04/2025	16:25:18					1.184,0	
12/04/2025	15:37:13					1.323,0	
23/04/2025	00:43:47	3	46	0,000		1.543,7	
26/04/2025	14:25:22	8	3	1,667	1,233	1.665,3	1.009,6
28/04/2025	06:59:10	11	2	1,500			
29/04/2025	07:31:24	13	1	2,000			
30/04/2025	08:03:02	14	1	1,000		1.788,5	
01/05/2025	09:50:45	17	1	3,000		1.831,2	
02/05/2025	06:30:31	19	1	2,000			
03/05/2025	08:57:39	20	1	1,000			
04/05/2025	09:39:09	22	1	2,000		1.938,1	
08/05/2025	06:32:23	28	4	1,500		2.078,1	
09/05/2025	22:30:26	30	1	2,000		2.149,4	
10/05/2025	23:21:11	32	1	2,000			
12/05/2025	05:22:22	35	2	1,500		2.280,6	
13/05/2025	11:11:44	37	1	2,000			
14/05/2025	21:06:54	39	1	2,000	1,935	2.405,9	1.153,6
16/05/2025	06:08:01	43	2	2,000		2.480,6	
17/05/2025	00:43:21	45	1	2,000			

Date (d)	Time (ICT-Hanoi)	Filtrate (m3)	Days (btwn.)	Avg (m ³ /d)	Avg (m ³ /m)	Electricity (kW/h/d)	Avg. Elt. (kW/h/m)
18/05/2025	12:44:49	50	1	5,000			
19/05/2025	10:26:11	52	1	2,000		2.664,7	
20/05/2025	10:39:23	54	1	2,000			
22/05/2025	10:44:40	54	2	0,000			
25/05/2025	13:55:22	55	3	0,333		2.868,3	
27/05/2025	05:46:42	56	2	0,500		2.950,1	
28/05/2025	07:24:09	58	1	2,000		2.984,8	
01/06/2025	02:58:16	62	4	1,000			
08/06/2025	04:03:21	69	7	1,000			
10/06/2025	21:33:37	72	2	1,500			
13/06/2025					1,189	3.731,4	1.728,3
15/06/2025	10:27:52	76	3	1,333			
19/06/2025	15:54:44	81	11	1,091		4.104,5	
24/06/2025	15:42:48	86	5	1,000			
29/06/2025	20:03:33	93	5	1,400			
01/07/2025	23:58:57	98	3	1,667		4.713,1	
15/07/2025	20:25:43	107	14	0,643		5.261,6	
18/07/2025	18:01:05					5.696,4	
22/07/2025	00:13:04	107	7	0,000	0,462		1.857,1
27/07/2025	11:14:41					6.240,6	
28/07/2025	13:33:38	107	6	0,000			
31/07/2025	05:52:16	107	3	0,000			
01/08/2025	14:44:42					6.570,2	
06/08/2025	04:11:32	111	6	0,667			
11/08/2025	17:38:03	114	5	0,600	0,333		1.019,7
15/08/2025	01:53:06	114	4	0,000			
21/08/2025	17:44:53	114	6	0,000			
26/08/2025	12:25:05	116	5	0,400			
01/09/2025	17:35:03	116	5	0,000		7.589,9	1.020,7
30/09/2025	12:26:00	120	29	0,138		8.610,6	

Date (d)	Time (ICT-Hanoi)	Filtrate (m3)	Days (btwn.)	Avg (m³/d)	Avg (m³/m)	Electricity (kW/h/d)	Avg. Elt. (kW/h/m)
Average Total		116	225	0,516		38,3	1.488,6
Average System Go		64	136	0,471	0,9	36,2	1.318,5

Appendix B.1: TestBed 1 (previous CEMM)

TestBed 1 emerged from preparatory work initially intended for another building. The planning process, from line drawings as the basis for the building through to detailed cost calculations, was developed for technical implementation on site. The plans were also used for submissions and approvals. The short-term change to the final TestBed 1 building was carried out without difficulty, as the detailed groundwork had already prepared the necessary knowledge of the relevant components and elements. The following technical drawings show the original TestBed 1. The building itself was roughly modelled digitally and presented in virtual reality as a before-and-after scenario for demonstration and communication purposes. The model cannot be described as a digital shadow or twin, as the necessary prerequisites were not fulfilled. The technical drawings also include information on the planting configurations of the containers based on native species, the design of the irrigation system, and details of commercially available products used for the on-site implementation.



!!! The test scenario is scheduled in operation till July 2025 max. It will be dismantled right after !!!

E-01 East Elevation

Neighbouring buildings reaching same height or even are higher.

red coloured sheet metal as roof cover. Extreme heat under facade, water exposed to the heat.

Louvers are most of the time closed. HVAC units serving daytime.

HVAC units on facade and balconies for each room.

E-01 East Elevation Green Curtain Wall Scenario

Planter B: 3.500 mm domestic bushy bamboo plants creating shade on the rooftop.

Planter A: big leafy plants and bushes up to a height of 3.500 mm covering the lower level and shade the roof.

Planter C: the smaller plants on overhangs and balconies roof hanging plates that create a vertical curtain wall around the building envelope. The distance is limited to the overhang of parapets and balconies are approx. 400 to 1.000 mm.

Built-in ATM container is the area for rain water tanks, ferti-lime and pump system.

E-02 South Elevation

Facade exposed to natural sun. Ventilation limited.

Narrow alley where ventilation stuck in summer time, but shading helps to reduce the heat.

E-02 South Elevation Green Curtain Wall Scenario

Exposed water tank will be shaded by bamboo garden. Optional white roof will be installed.

CEMM balconies for testing Green

2nd Floor balconies as reference without Green

water tanks and Wb Smart Pump

All measures MUST BE DOUBLE CHECKED BY MANUFACTURER / SUPPLIER / SUBCONTRACTOR

101 GA KHUỖI TỈNH QUẢNG BÌNH THƯỜNG KIỆT - HÀ NỘI - VIỆT NAM

All Measures based on: Hersteller: CEMM - Fachunternehmen: page: 0001 - 0001

SUA - Smart Urban Areas
Tübingen T2

67EXIS001A

TU Dortmund University
Research Center for
Environmental Monitoring and Modelling
Campus Straße 10
44227 Dortmund
Germany
www.ema.dtu.dortmund.de

Wilo SE
Wiloars 1
4430 Dortmund
Germany
www.wilo.com

HDB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Modelling
204 Nguyen Thi Street
Thanh Xuan District
Hanoi
Vietnam

DRAFT

F
E
D
C
B
A

16.11.2023

Author: Martin Schwanke, BIM TU Dortmund University, 11.02.2023

Project: CEMM Green

Project No: 67EXIS001A

Project Location: Dortmund, Germany

Project Start: 16.11.2023

Project End: 16.11.2023

Concept: CEMM GREEN

Elevations: Now - Test

A.02.1

Micro-Climature Analysis by ENVI_met for the area around CEMM building / Phân tích vi khí hậu của ENVI_met cho khu vực xung quanh tòa nhà CEMM

a) Δ Facade Temperature [°C]

b) Δ Energy needed to keep building temperature inside constant (24°C) [W]

c) Δ LW Radiation Energy Balance [W/m²]

Building Greening Scenario for CEMM-Building on a Hot Summer Day

CEMM-Building

HUSCO

d) Simulation Parameters

Duration: 24 h on 29th June
Resolution: 3 m (x,y,z)
Output Interval: 1h
Tmax: 39°C
Tmin: 29°C
Software: ENVI_met 5.5.1

source: Martin Schwanke, BIM TU Dortmund University, 11.02.2023

SUA - Smart Urban Areas
Tübingen T2

67EXIS001A

TU Dortmund University
Research Center for
Environmental Monitoring and Modelling
Campus Straße 10
44227 Dortmund
Germany
www.ema.dtu.dortmund.de

Wilo SE
Wiloars 1
4430 Dortmund
Germany
www.wilo.com

HDB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Modelling
204 Nguyen Thi Street
Thanh Xuan District
Hanoi
Vietnam

DRAFT

F
E
D
C
B
A

16.11.2023

Author: Martin Schwanke, BIM TU Dortmund University, 11.02.2023

Project: CEMM Green

Project No: 67EXIS001A

Project Location: Dortmund, Germany

Project Start: 16.11.2023

Project End: 16.11.2023

Concept: CEMM GREEN

Elevations: Now - Test

Micro Climate Analysis

A.03.1



SUA - Smart Urban Areas
Tübingen 72

67EXIS001A

TU Dortmund University
Research Center for
Environmental Monitoring and Modelling
Campus Straße 101 44227 Dortmund
Germany
www.cemmm.de

Wilo SE
Wilostr. 1
44129 Dortmund
Germany
www.wilo.com

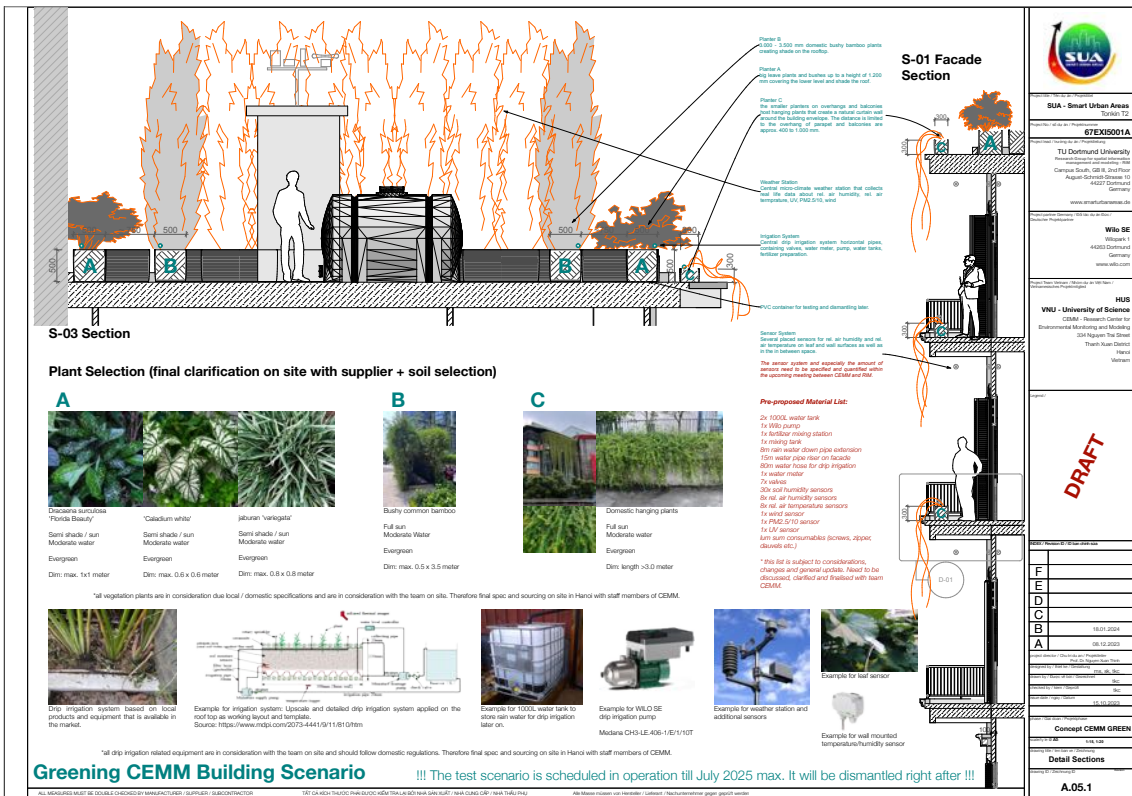
HB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Modelling
324 Nguyen Thi Street
Thuan Xuan District
Hanoi
Vietnam

DRAFT

Concept CEMM GREEN

Visualisations

A.04.1



SUA - Smart Urban Areas
Tübingen 72

67EXIS001A

TU Dortmund University
Research Center for
Environmental Monitoring and Modelling
Campus Straße 101 44227 Dortmund
Germany
www.cemmm.de

Wilo SE
Wilostr. 1
44129 Dortmund
Germany
www.wilo.com

HB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Modelling
324 Nguyen Thi Street
Thuan Xuan District
Hanoi
Vietnam

DRAFT

Concept CEMM GREEN

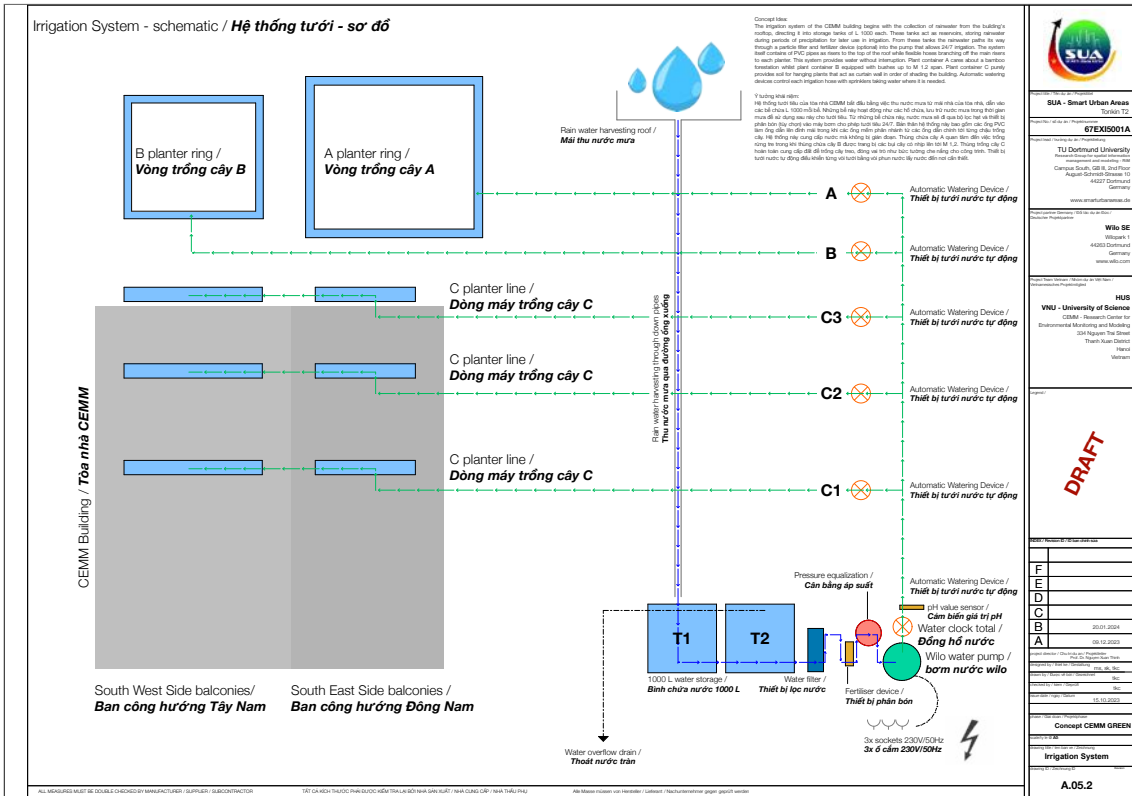
Detail Sections

A.05.1

Greening CEMM Building Scenario

!!! The test scenario is scheduled in operation till July 2025 max. It will be dismantled right after !!!

All drawings shall be double checked by MANUFACTURER / SUPPLIER / SUBCONTRACTOR. TU CA HOY HOC VO THU QUOC HAI PHU THAI A SO HOA BINH KUT - HOA GIANG DEP - HOA THAI PHU. All photos taken on location. Content: "Technische Zeichnung" page: 0/001/001



SUA - Smart Urban Area
Torbik 72

67EX15001A

TU Dortmund University
Environmental Engineering and Robotics
Campus Escheweg, 44227 Dortmund
August-Schmidt-Strasse 10
44227 Dortmund
Germany
www.tu-dortmund.de

Wilo SE
Wilostr. 1
4400 Dortmund
Germany
www.wilo.com

HRB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Robotics
324 Nguyen Thi Street
Thuan Xuan District
Ha Noi
Vietnam

DRAFT

Concept CEMM GREEN

Irrigation System

A.05.2



SUA - Smart Urban Area
Torbik 72

67EX15001A

TU Dortmund University
Environmental Engineering and Robotics
Campus Escheweg, 44227 Dortmund
August-Schmidt-Strasse 10
44227 Dortmund
Germany
www.tu-dortmund.de

Wilo SE
Wilostr. 1
4400 Dortmund
Germany
www.wilo.com

HRB
WU - University of Science
CEMM - Research Center for
Environmental Monitoring and Robotics
324 Nguyen Thi Street
Thuan Xuan District
Ha Noi
Vietnam

DRAFT

Concept CEMM GREEN

Plant System

A.05.3

Appendix B.2: TestBed 2

The technical documentation for TestBed 2 is the most comprehensive within the project. Building on the operational experience gained from Tonkin 2 and TestBed 1, the design and implementation of TestBed 2 incorporated all relevant sensor systems and technical components defined in the research framework. Despite minor data inconsistencies, it provided the most complete and up-to-date dataset across the study. Based on this material, a three-dimensional digital shadow of the building was developed and subsequently exported into augmented and virtual reality environments for visualisation, communication, and simulation purposes. The geometric accuracy of the model - supported through drone-based photogrammetry - demonstrates the reliability of current VR workflows for environmental and spatial assessment.

This technical set enabled the precise planning and configuration of sensor layouts, weather station integration, roof and facade greening measures, calculations and the installation of the WA-MBR-TB225 water filtration unit. As such, TestBed 2 represents a reference case for scaling vegetated buildings and circular economy for water cycles. At least it built the ground for implementation.



Detail D-10, exterior wall section

- Small overhang in front of sliding door
- Phần nhỏ nhô ra phía trước cửa trượt
- Ridge layer
- 100mm floor
- 30mm concrete
- 100mm concrete
- Lớp nền
- Sàn 100mm
- Vữa 30mm
- Bê tông 100mm
- Concrete beam
- Cột bê tông
- Recessed ceiling, 90mm
- Tiền âm trần, 90mm
- Common brick, traditional fired
- Gạch thông thường, nung theo phương pháp truyền thống
- Outdoor unit air con
- Máy lạnh ngoài trời
- Sliding door, aluminum frame not insulated, 2-layer glass
- Cửa trượt nhôm không cách nhiệt, kính 2 lớp
- Khung nhôm không cách nhiệt, kính 2 lớp
- Black balustrade, metal
- Lan can màu đen, kim loại
- Ceramic floor tiles go through. No floor separation
- Gạch lát sàn lát xuyên qua. Không có sự tách biệt giữa lát sàn.

Construction materials - common bricks:
 Vật liệu xây dựng - gạch thông thường:

Color palette:

Material list:

Code	Name	Unit	Quantity
1	Common brick	m ²	1.00
2	Concrete beam	m ³	0.10
3	Recessed ceiling	m ²	1.00
4	Outdoor unit air con	unit	1.00
5	Sliding door	m ²	1.00
6	Black balustrade	m	1.00
7	Ceramic floor tiles	m ²	1.00

Detail D-8, exterior wall - floor section

Detail D-9, exterior wall - basement - air space section

Material list (continued):

Code	Name	Unit	Quantity
8	Concrete	m ³	0.10
9	Recessed ceiling	m ²	1.00
10	Outdoor unit air con	unit	1.00
11	Sliding door	m ²	1.00
12	Black balustrade	m	1.00
13	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
14	Concrete	m ³	0.10
15	Recessed ceiling	m ²	1.00
16	Outdoor unit air con	unit	1.00
17	Sliding door	m ²	1.00
18	Black balustrade	m	1.00
19	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
20	Concrete	m ³	0.10
21	Recessed ceiling	m ²	1.00
22	Outdoor unit air con	unit	1.00
23	Sliding door	m ²	1.00
24	Black balustrade	m	1.00
25	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
26	Concrete	m ³	0.10
27	Recessed ceiling	m ²	1.00
28	Outdoor unit air con	unit	1.00
29	Sliding door	m ²	1.00
30	Black balustrade	m	1.00
31	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
32	Concrete	m ³	0.10
33	Recessed ceiling	m ²	1.00
34	Outdoor unit air con	unit	1.00
35	Sliding door	m ²	1.00
36	Black balustrade	m	1.00
37	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
38	Concrete	m ³	0.10
39	Recessed ceiling	m ²	1.00
40	Outdoor unit air con	unit	1.00
41	Sliding door	m ²	1.00
42	Black balustrade	m	1.00
43	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
44	Concrete	m ³	0.10
45	Recessed ceiling	m ²	1.00
46	Outdoor unit air con	unit	1.00
47	Sliding door	m ²	1.00
48	Black balustrade	m	1.00
49	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
50	Concrete	m ³	0.10
51	Recessed ceiling	m ²	1.00
52	Outdoor unit air con	unit	1.00
53	Sliding door	m ²	1.00
54	Black balustrade	m	1.00
55	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
56	Concrete	m ³	0.10
57	Recessed ceiling	m ²	1.00
58	Outdoor unit air con	unit	1.00
59	Sliding door	m ²	1.00
60	Black balustrade	m	1.00
61	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
62	Concrete	m ³	0.10
63	Recessed ceiling	m ²	1.00
64	Outdoor unit air con	unit	1.00
65	Sliding door	m ²	1.00
66	Black balustrade	m	1.00
67	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
68	Concrete	m ³	0.10
69	Recessed ceiling	m ²	1.00
70	Outdoor unit air con	unit	1.00
71	Sliding door	m ²	1.00
72	Black balustrade	m	1.00
73	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
74	Concrete	m ³	0.10
75	Recessed ceiling	m ²	1.00
76	Outdoor unit air con	unit	1.00
77	Sliding door	m ²	1.00
78	Black balustrade	m	1.00
79	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
80	Concrete	m ³	0.10
81	Recessed ceiling	m ²	1.00
82	Outdoor unit air con	unit	1.00
83	Sliding door	m ²	1.00
84	Black balustrade	m	1.00
85	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
86	Concrete	m ³	0.10
87	Recessed ceiling	m ²	1.00
88	Outdoor unit air con	unit	1.00
89	Sliding door	m ²	1.00
90	Black balustrade	m	1.00
91	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
92	Concrete	m ³	0.10
93	Recessed ceiling	m ²	1.00
94	Outdoor unit air con	unit	1.00
95	Sliding door	m ²	1.00
96	Black balustrade	m	1.00
97	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
98	Concrete	m ³	0.10
99	Recessed ceiling	m ²	1.00
100	Outdoor unit air con	unit	1.00
101	Sliding door	m ²	1.00
102	Black balustrade	m	1.00
103	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
104	Concrete	m ³	0.10
105	Recessed ceiling	m ²	1.00
106	Outdoor unit air con	unit	1.00
107	Sliding door	m ²	1.00
108	Black balustrade	m	1.00
109	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
110	Concrete	m ³	0.10
111	Recessed ceiling	m ²	1.00
112	Outdoor unit air con	unit	1.00
113	Sliding door	m ²	1.00
114	Black balustrade	m	1.00
115	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
116	Concrete	m ³	0.10
117	Recessed ceiling	m ²	1.00
118	Outdoor unit air con	unit	1.00
119	Sliding door	m ²	1.00
120	Black balustrade	m	1.00
121	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
122	Concrete	m ³	0.10
123	Recessed ceiling	m ²	1.00
124	Outdoor unit air con	unit	1.00
125	Sliding door	m ²	1.00
126	Black balustrade	m	1.00
127	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
128	Concrete	m ³	0.10
129	Recessed ceiling	m ²	1.00
130	Outdoor unit air con	unit	1.00
131	Sliding door	m ²	1.00
132	Black balustrade	m	1.00
133	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
134	Concrete	m ³	0.10
135	Recessed ceiling	m ²	1.00
136	Outdoor unit air con	unit	1.00
137	Sliding door	m ²	1.00
138	Black balustrade	m	1.00
139	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
140	Concrete	m ³	0.10
141	Recessed ceiling	m ²	1.00
142	Outdoor unit air con	unit	1.00
143	Sliding door	m ²	1.00
144	Black balustrade	m	1.00
145	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
146	Concrete	m ³	0.10
147	Recessed ceiling	m ²	1.00
148	Outdoor unit air con	unit	1.00
149	Sliding door	m ²	1.00
150	Black balustrade	m	1.00
151	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
152	Concrete	m ³	0.10
153	Recessed ceiling	m ²	1.00
154	Outdoor unit air con	unit	1.00
155	Sliding door	m ²	1.00
156	Black balustrade	m	1.00
157	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
158	Concrete	m ³	0.10
159	Recessed ceiling	m ²	1.00
160	Outdoor unit air con	unit	1.00
161	Sliding door	m ²	1.00
162	Black balustrade	m	1.00
163	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
164	Concrete	m ³	0.10
165	Recessed ceiling	m ²	1.00
166	Outdoor unit air con	unit	1.00
167	Sliding door	m ²	1.00
168	Black balustrade	m	1.00
169	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
170	Concrete	m ³	0.10
171	Recessed ceiling	m ²	1.00
172	Outdoor unit air con	unit	1.00
173	Sliding door	m ²	1.00
174	Black balustrade	m	1.00
175	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
176	Concrete	m ³	0.10
177	Recessed ceiling	m ²	1.00
178	Outdoor unit air con	unit	1.00
179	Sliding door	m ²	1.00
180	Black balustrade	m	1.00
181	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
182	Concrete	m ³	0.10
183	Recessed ceiling	m ²	1.00
184	Outdoor unit air con	unit	1.00
185	Sliding door	m ²	1.00
186	Black balustrade	m	1.00
187	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):

Code	Name	Unit	Quantity
188	Concrete	m ³	0.10
189	Recessed ceiling	m ²	1.00
190	Outdoor unit air con	unit	1.00
191	Sliding door	m ²	1.00
192	Black balustrade	m	1.00
193	Ceramic floor tiles	m ²	1.00

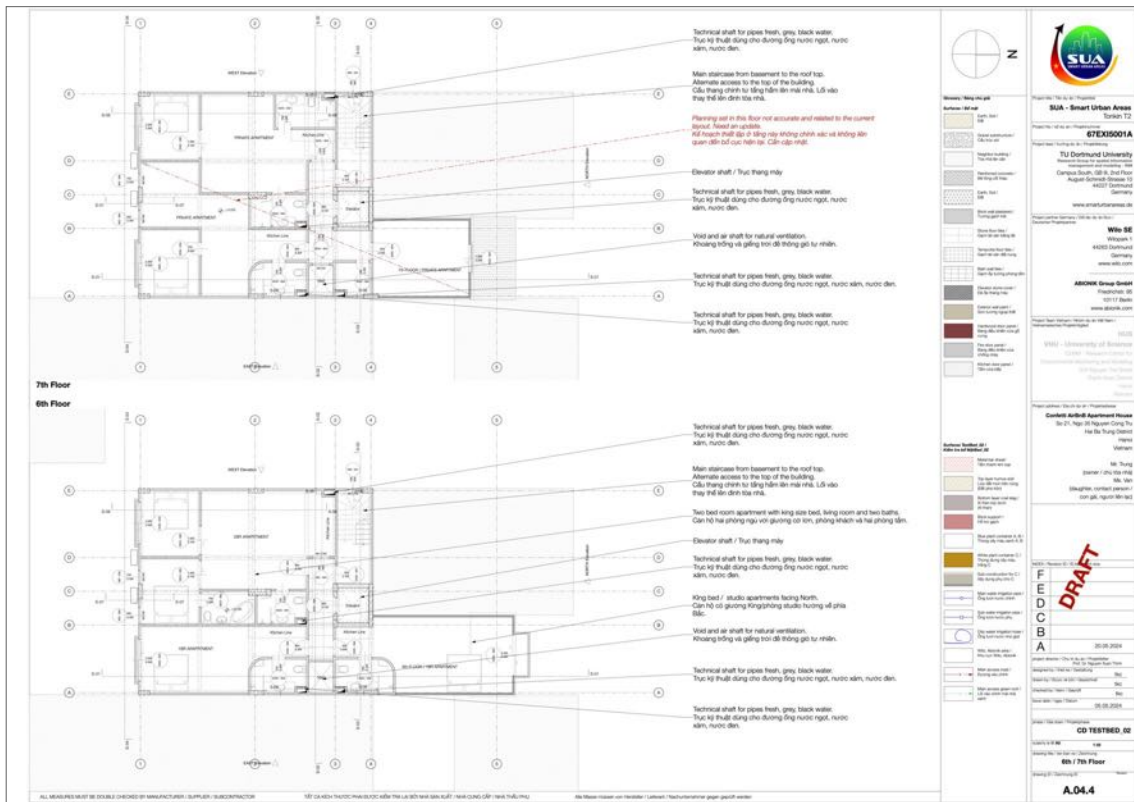
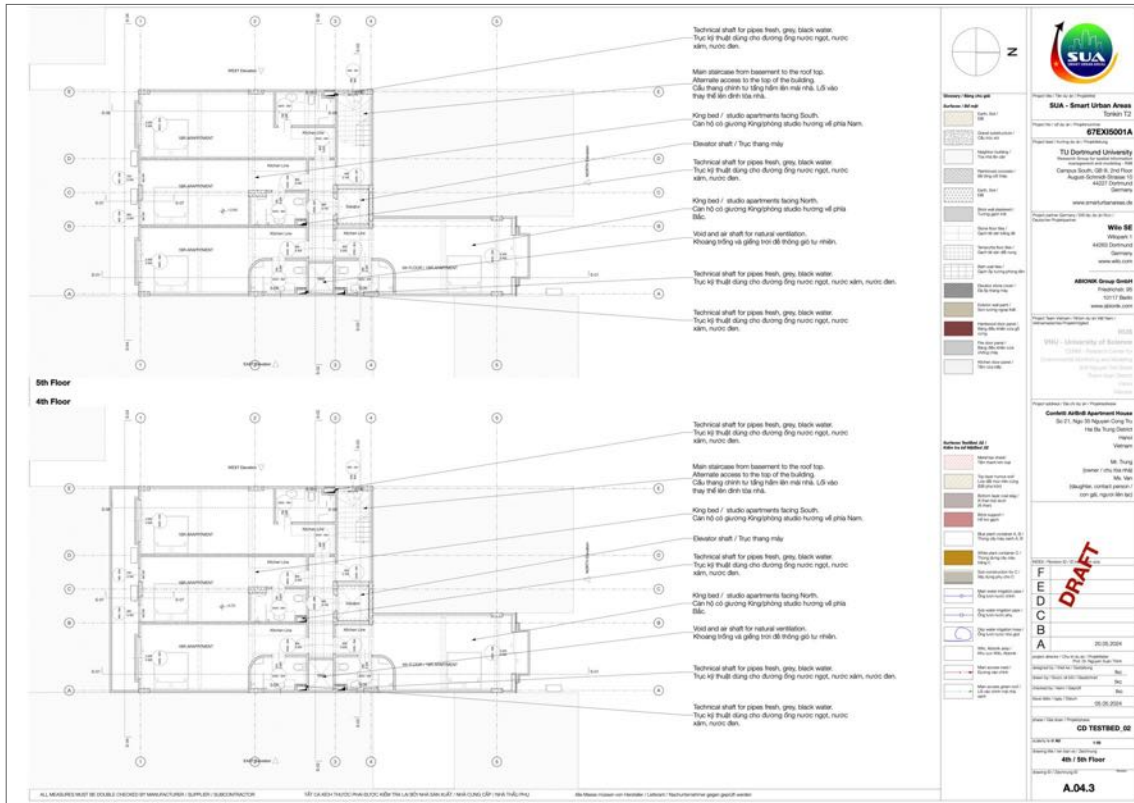
Color palette (continued):

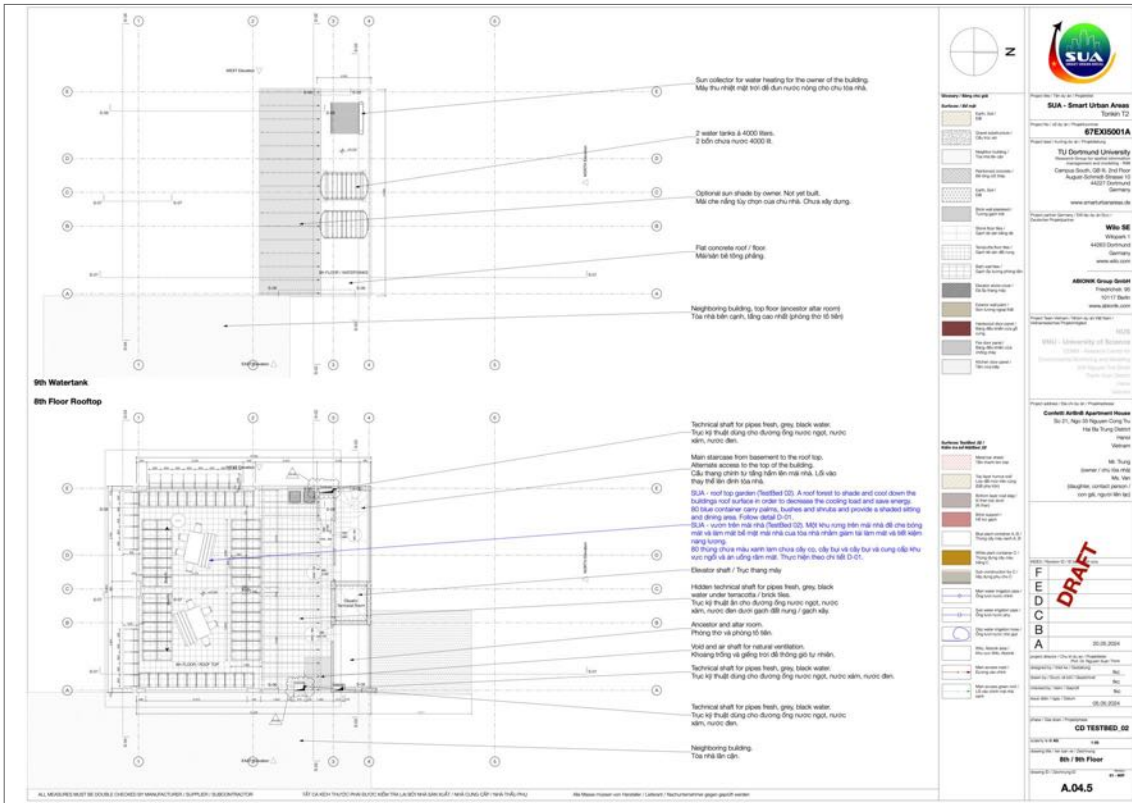
Material list (continued):

Code	Name	Unit	Quantity
194	Concrete	m ³	0.10
195	Recessed ceiling	m ²	1.00
196	Outdoor unit air con	unit	1.00
197	Sliding door	m ²	1.00
198	Black balustrade	m	1.00
199	Ceramic floor tiles	m ²	1.00

Color palette (continued):

Material list (continued):





Elevations / Mặt tiền

Ansichten:
Die Gebäußeansichten stellen den aktuellen Zustand dar.

Livret xem:
Livret xem tòa nhà thể hiện trạng thái hiện tại.

Sections / Mặt dựng

Building sections:
The building sections show specific cross-sections that are necessary for further planning.

Mặt cắt tòa nhà:
Mặt cắt tòa nhà hiển thị các mặt cắt cụ thể cần thiết cho việc lập kế hoạch tiếp theo.

ALL MEASUREMENTS IN DOUBLE DIMENSION (MANUFACTURER / SUPPLIER / SUBCONTRACTOR) | **Tất cả các phép đo đều phải được hiển thị bằng đơn vị kép (nhà sản xuất / nhà cung cấp / nhà thầu phụ)** | *All Measurements are in Double Dimension (Manufacturer / Supplier / Subcontractor)*

Section S-01 Current Condition

Section S-01 AFTER: Green & Water treatment installation

DWS weather station.
Trạm thời tiết DWS.

Green roof top garden / forest to shade and cool the building.
Vườn mái thượng tầng nhà để che bóng mát cho tòa nhà.

Abate® grey/black water cleaning unit.
Thiết bị xử lý nước thải màu Abate®.

Abate® water treatment pump and tanks.
Máy bơm lọc nước màu Wate Mediana và bồn chứa.

SUA - Smart Urban Areas
Tầng 12

Project No. 67EX0001A

Client: **TU Dortmund University**
Friedrich-Schiller-Str. 181
Campus South, SE-9, 3rd Floor
Adolph-Diesterweg 15
44227 Dortmund
Germany
www.umweltumwelts.de

Project Manager: **Wilo SE**
Wilostr. 1
44885 Dortmund
Germany
www.wilo.com

Architect: **ABOW Group GmbH**
Hauptstr. 66
10117 Berlin
www.abow.com

Client Representative: **WU - University of Statistics**
WU - Universität für Wirtschaftsinformatik und Statistik
Wirtschaftsuniversität Wien
Alte Universitätsstr. 1
1040 Wien
Austria

Contract: **Abate® Apartment House**
St. 21, Ng. 20 Nguyen Cong Tho
Khu Đô Thị Tân Định
Hải Phòng
Vietnam

Contract Manager: **M. Tung**
General / Ông Tung
Abate®
Bằng Sơn, Quận Cầu Giấy /
Số 10, Ng. Nguyễn Văn Linh

DRAFT

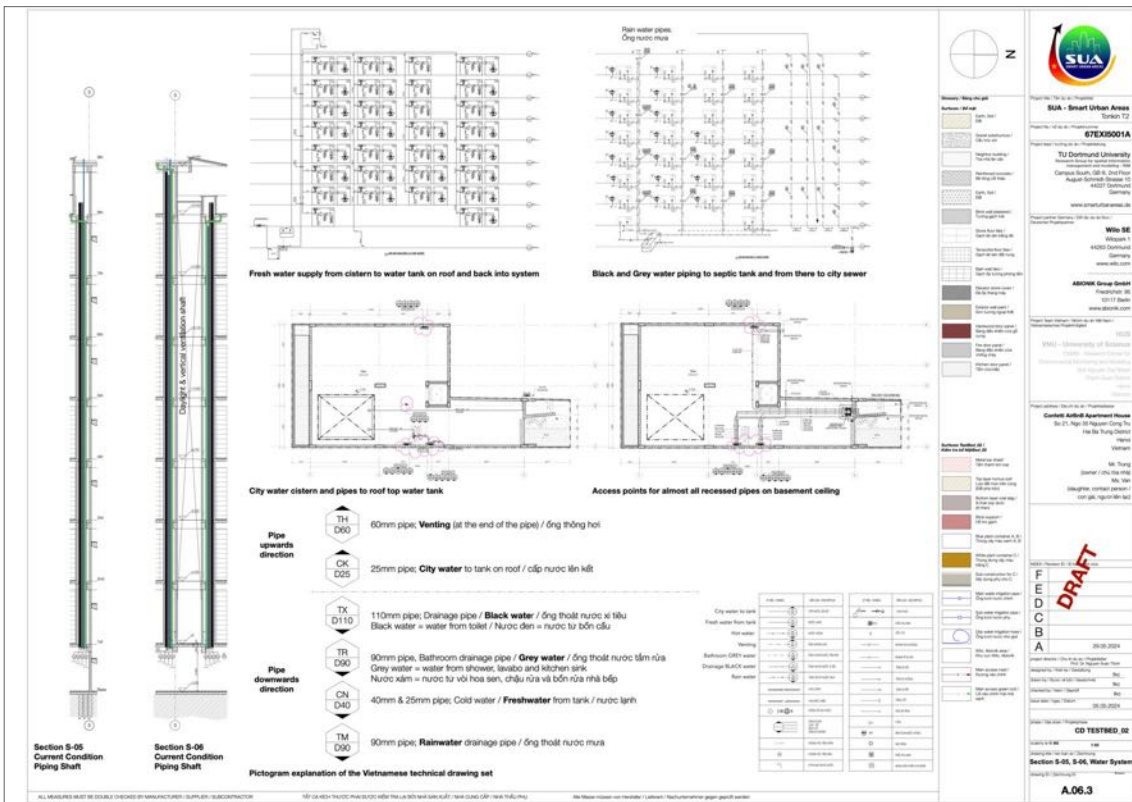
28.08.2024

CD TESTBED_02

Section S-01

A.06.1

ALL MEASUREMENTS IN DOUBLE DIMENSION (MANUFACTURER / SUPPLIER / SUBCONTRACTOR) | **Tất cả các phép đo đều phải được hiển thị bằng đơn vị kép (nhà sản xuất / nhà cung cấp / nhà thầu phụ)** | *All Measurements are in Double Dimension (Manufacturer / Supplier / Subcontractor)*



Green concept / Khái niệm xanh

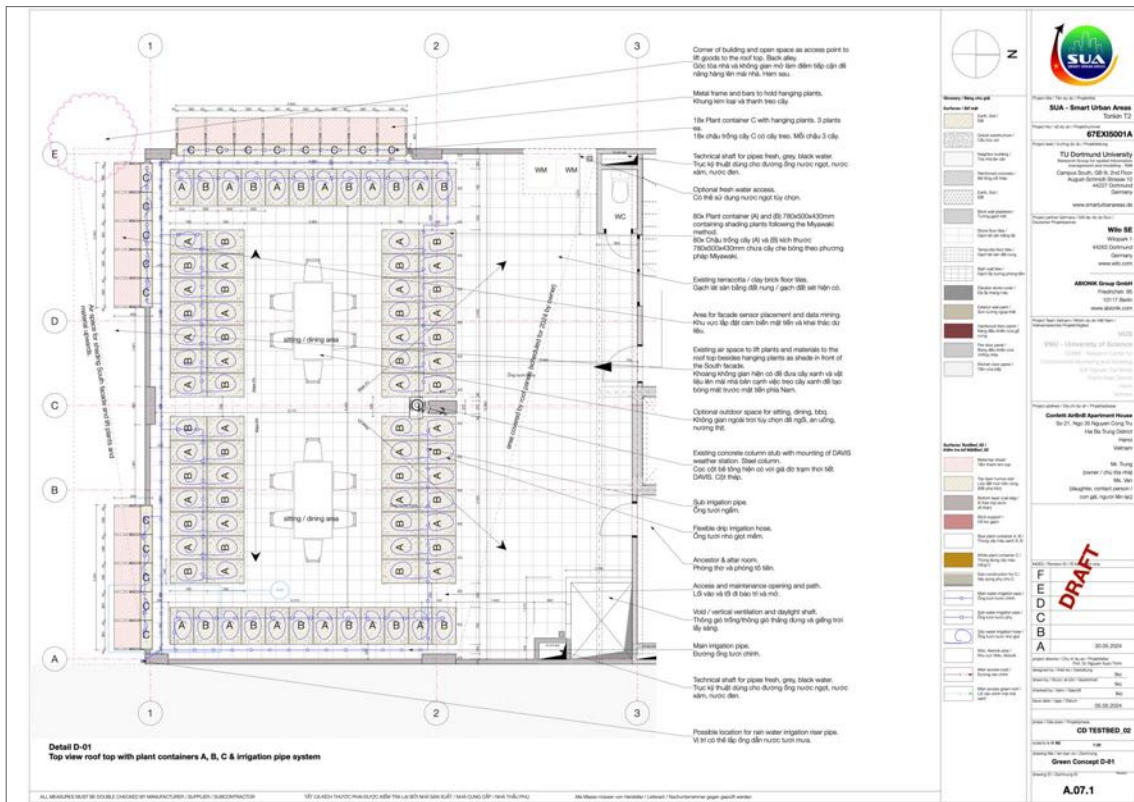
Green concept:

The green concept of the TestBed_02 provides a detailed overview of the techniques that will be used to gain scientific knowledge about the extent to which the second skin of the building made of plants can reduce cooling and thus reduce the cooling load from air conditioning systems. In this concept, the Miyawaki method of creating a fast growing forest of native trees and shrubs is used to quickly create a shading layer on the green roof that cools the building from above.

Khái niệm xanh:

Khái niệm xanh của TestBed_02 cung cấp tổng quan chi tiết về các kỹ thuật sẽ được sử dụng để có được kiến thức khoa học về mức độ mà lớp vỏ thứ hai của tòa nhà làm bằng cây xanh có thể làm giảm khả năng làm mát và do đó giảm tải làm mát từ hệ thống điều hòa không khí. Trong khái niệm này, phương pháp Miyawaki tạo ra một khu rừng cây và cây bụi bản địa phát triển nhanh được sử dụng để nhanh chóng tạo ra một lớp che nắng trên mái nhà xanh giúp làm mát tòa nhà từ phía trên.

ALL MEASURES MUST BE DOUBLE CHECKED BY MANUFACTURER, SUPPLIER, SUBCONTRACTOR. TẤT CẢ CÁC GIẢI PHÁP VÀ CÁC KỸ THUẬT VÀ CÁC SẢN PHẨM SỬ DỤNG PHẢI ĐƯỢC KIỂM TRA VÀ KIỂM NGHIỆM LẠI. Mọi Measure phải có Hersteller / Lieferant / Fachunternehmen phải giấy viết nước.



1 DAVIS Vantage Pro2 weather station on peak of building
Trạm thời tiết DAVIS Vantage Pro2 trên đỉnh tòa nhà.

2

Examples from TestBed_01
Ví dụ từ TestBed_01

Plant configuration container (A) + (B)
Cấu hình máy chứa (A) + (B)

Ecosystem after planting
Hệ sinh thái sau khi trồng

Plant container (C) for hanging plants
Chậu trồng cây (C) treo cây

Main irrigation pipe in grey
Cống tưới chính màu xám

Sub irrigation pipe
Cống tưới phụ

Flexible drip irrigation hose
Cống tưới nhỏ giọt mềm

Detail D-02 A
Section through plant containers at roof top

Butterfly pain
Cáp Cúc Lưu Ý

Common fern
Cây Sừng K

Blood clamshell
Cây Sò Huyết

Spider plant
Cây Nhện

Hanging plant
Cây Cúc Ban Ai Đa

Detail D-02 B
Ecosystem configuration of the plant containers (A), (B), (C)
Cấu hình hệ sinh thái của các thùng chứa thực vật (A), (B), (C)

Detail D-02 C
The containers (A) and (B) are arranged laterally and offset one behind the other
Các thùng chứa (A) và (B) được sắp xếp theo chiều ngang và lệch nhau

Green Concept D-02 A, B, C

A.07.2

South elevation after greening

South elevation after greening w/ rain use water irrigation riser

West elevation after greening

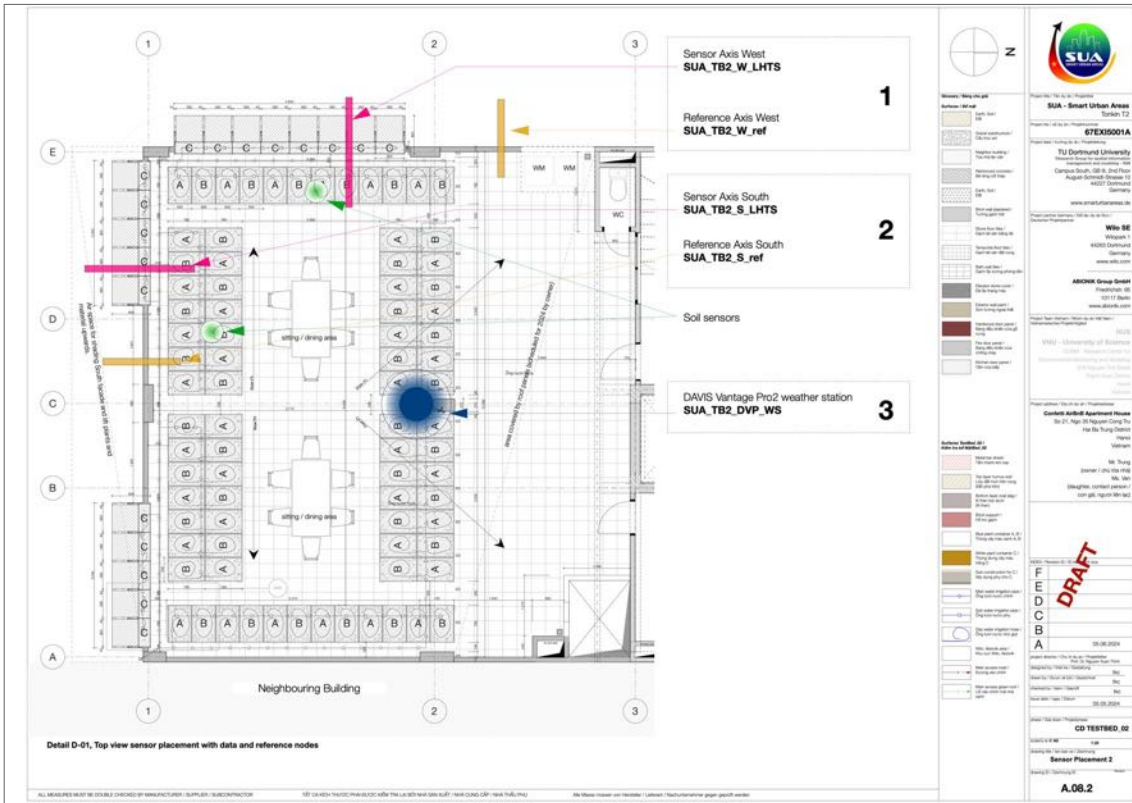
Butterfly pain
Cáp Cúc Lưu Ý

Hanging plant
Cây Cúc Ban Ai Đa

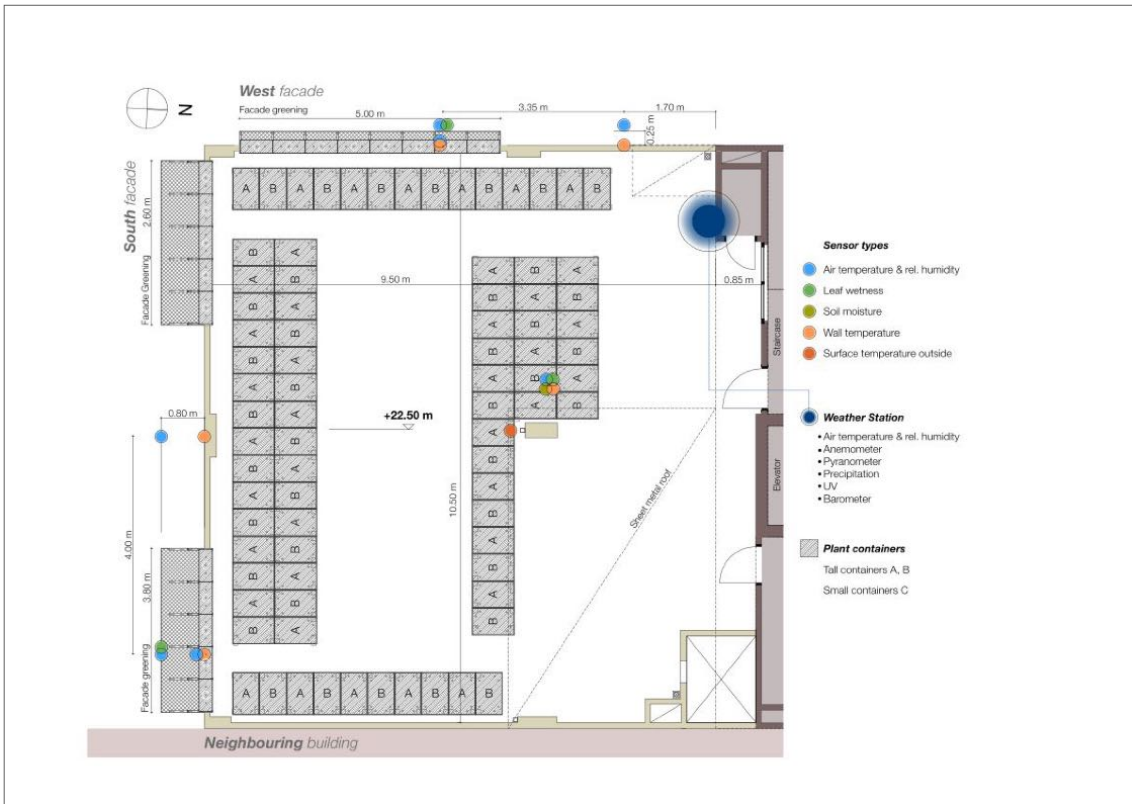
Optimal position for rainwater irrigation riser pipe
Vị trí tối ưu cho ống dẫn nước mưa

Green Elevations South / West

A.07.3



Update - Site improvements



Visuals / Hình ảnh















Visualizations:

The virtually created images of the building support the overall concept for TestBed_02 and the requirements of the SUA project in order to document and demonstrate building optimizations across topics.

Hình ảnh trực quan:

Hình ảnh ảo của tòa nhà hỗ trợ khái niệm chung cho TestBed_02 và các yêu cầu của dự án SUA nhằm ghi lại và chứng minh các ưu ưu hóa tòa nhà trên nhiều chủ đề.

ALL RIGHTS RESERVED BY DOUBLE CREATED BY MANUFACTURER / SUPPLIER / SUBCONTRACTOR | 100% QUALITY CONTROLLED BY THE CLIENT AND THE CLIENT'S REPRESENTATIVE | 100% DESIGN COPY - NOT TO BE REPRODUCED | 100% DESIGN COPY - NOT TO BE REPRODUCED

 <p>Current situation of roof top and newly built neighboring building Tình hình hiện tại của mái nhà và tòa nhà lân cận mới xây dựng</p>	 <p>Future Confetti Homestay building in the afternoon hours in sunset Tòa nhà Future Confetti Homestay vào buổi chiều hoàng hôn</p>	 <p>Confetti building in the morning sunrise Tòa nhà giấy sụn vào buổi sáng mặt trời mọc</p>	 <p>Material - Bảng màu vật liệu</p> <ul style="list-style-type: none"> Concrete - Bê tông Dark concrete - Bê tông tối Light concrete - Bê tông sáng Dark grey - Xám tối Light grey - Xám sáng White - Trắng Green - Xanh lá Blue - Xanh dương Red - Đỏ Yellow - Vàng Orange - Cam Purple - Tím Black - Đen 	 <p>SUA - Smart Urban Areas Tầm nhìn 12</p> <p>67EXIX001A</p> <p>TU Dortmund University Institute for Smart Urban Areas Campus South, 28-6, 2nd Floor Lage: 44227 Dortmund Germany www.smarturbanareas.de</p> <p>Wilo SE Wilo SE 44289 Dortmund Germany www.wilo.com</p> <p>ALBION Group GmbH Hauptstadtstr. 46 50177 Bonn Germany www.albion.com</p> <p>IBS IBS University of Business Institute for Smart Urban Areas Campus South, 28-6, 2nd Floor Lage: 44227 Dortmund Germany www.ibs.de</p> <p>Confetti Apartment Houses Dr. Dr. Nguyen Cong Thuy 100 Ba Thuan Street Hanoi Vietnam M. Trung Central 17th Floor 100 Ba Thuan Street Hanoi Vietnam (Singapore contact number) +65 90 90 90 90</p> <p>CD TESTBED_02 Visuals 1</p> <p>A.10.1</p>
 <p>Confetti building at noon Tòa nhà giấy sụn vào buổi trưa</p>	 <p>Confetti building in the earliest hour of the day Xây dựng giấy sụn vào giờ đầu tiên của ngày</p>	 <p>Confetti building seen from cloudy South West Tòa nhà Confetti nhìn từ phía Tây Nam nhiều mây</p>		
 <p>Confetti building seen from sunny South West Tòa nhà Confetti nhìn từ phía Tây Nam đầy nắng</p>	 <p>Confetti building bird view at sunset Ngắm nhìn xây dựng bằng giấy sụn lúc hoàng hôn</p>	 <p>Afternoon hour on the green shaded roof top Giờ chiều trên mái nhà xanh mát</p>		
 <p>Late sunset moment on the roof top Khoảnh khắc hoàng hôn muộn trên mái nhà</p>	 <p>Rainy day on the roof top Ngày mưa trên mái nhà</p>	 <p>Close up from South at 10 am Cận cảnh từ phía Nam lúc 10 giờ sáng</p>		

Product sourcing / Nguồn gốc sản phẩm

Product selection:
The following pages show some of the products that are used.

Lựa chọn sản phẩm:
Các trang sau đây hiển thị một số sản phẩm được sử dụng.

ALL MEASUREMENTS ARE DOUBLE CHECKED BY MANUFACTURER / SUPPLIER / SUBCONTRACTOR. Tất cả các đo lường đều được kiểm tra lại bởi nhà sản xuất / nhà cung cấp / nhà thầu phụ. Alle Messungen sind ebenfalls / ebenfalls / Nachprüfergebnisse gegen geprüft werden.

Product examples similar to TestBed_01 / Ví dụ sản phẩm tương tự như TestBed_01



Blue plant container (A) & (B) - exact product, local supplier Hanoi.
Chậu cây xanh (A) & (B) - sản phẩm chính xác, nhà cung cấp địa phương Hà Nội.



80 QTY
Dimension / Kích thước
700 x 500 x 430 mm

Example from TestBed_01 at Yen Lang.
Ví dụ từ TestBed_01 tại Yên Lang.

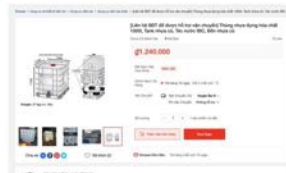


Plant container (C) as example. If possible in white or light beige color.
Ví dụ, chậu cây (C). Nếu có thể, hãy chọn màu trắng hoặc màu be nhạt.



18 QTY
Required dimension / Kích thước yêu cầu
~500 x 300 x 200 mm

Example from TestBed_01 at Yen Lang. This container is too small.
Ví dụ từ TestBed_01 tại Yên Lang. Container này quá nhỏ.



Exact 1000L water tank to store rainwater and treated water (Abionik).
Đúng chậu nước Exact 1000L để chứa nước mưa và nước đã qua xử lý (Abionik).

6 QTY



1 QTY

Wilo Smart Pump Medana. Already in Hanoi and prepared for rainwater irrigation systems.
Máy bơm thông minh Wilo Medana. Đã có mặt tại Hà Nội và chuẩn bị cho hệ thống tưới nước mưa.



Orange colored lashing strap
Dây buộc màu cam



12 QTY
Dimension / Kích thước
50 mm x 8 m

Example from TestBed_01 at Yen Lang.
Ví dụ từ TestBed_01 tại Yên Lang.



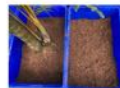
150 QTY

Common bricks
Gạch thông thường



Bottom and drain layer: Coal slag
Xỉ than

5,50 m³



Top and humus layer:
Đất trồng (đất, mùn, humic)

11,00 m³

Price orientation / Định hướng giá

SUA - Smart Urban Areas
Smart T2
67EX0001A
TU Dortmund University
Wilo SE
ABONK Group GmbH

CD TESTBED_01
Product sourcing 1
A.11.1

ALL MEASUREMENTS ARE DOUBLE CHECKED BY MANUFACTURER / SUPPLIER / SUBCONTRACTOR. Tất cả các đo lường đều được kiểm tra lại bởi nhà sản xuất / nhà cung cấp / nhà thầu phụ. Alle Messungen sind ebenfalls / ebenfalls / Nachprüfergebnisse gegen geprüft werden.

WLO / Abokiv:
 Water được tái sử dụng và được lọc sạch để sử dụng cho hệ thống tưới nước tự động. Nước này được lưu trữ trong bể chứa nước sạch và được trộn với nước mưa trong các bể chứa nước sạch. Nước này sau đó được sử dụng cho hệ thống tưới nước tự động.

The system is designed to utilize rainwater and greywater for automatic irrigation. The water is stored in the water tanks on the left. This water is also used for the automatic irrigation system.

Trạm nước làm sạch và lọc nước mưa, nước xám và nước đen cho đến khi có thể tưới nước mưa phân vụ được lưu trữ ở cuối và trộn với nước mưa trong các bể chứa nước sạch. Nước này sau đó được sử dụng cho hệ thống tưới nước tự động.

Hệ thống này được thiết kế để dự trữ nước và trộn với nước mưa cho tưới nước phân vụ và lưu trữ nước mưa phân vụ để tưới nước phân vụ. Hệ thống này bơm tới 7.5 mét nước phân vụ mỗi ngày.

Access to 30A, 400 V POWER Supply / Truy cập vào Nguồn điện 30A, 400V
 Lưu ý: Điện của tòa nhà có thể được cung cấp cho đây này không?

Advantage: ACCESS to pipes and exit
 4x DN 110mm PVC pipes for drainage water. Main pipes for all bath rooms, toilets, kitchen and tap water

Lưu ý: TIẾP CẬN đường ống và lối ra
 4 ống PVC DN 110mm cho hệ thống thoát nước. Ống chính cho tất cả các phòng tắm, nhà vệ sinh, nhà bếp và nước mưa

On November 6, 2024, the ASU/LPT situation in the Corbett apartment building in close cooperation with the Abokiv WLO team and TU Dortmund. The work on this system was completed in the beginning of December and shipped to Vietnam in mid-January. Installation in Corbett from mid-February 2025.

The following work must be considered on site by the SUA / WLO Haven team:

- Filter mat 10 mm as Rain/WWS/BMU protection and noise insulator
- Clear power connection of 33A/400V
- Install additional ventilation
- Install webcam for reading the data on the screen or clarify service with WLO Haven for reading the data.
- Daily manual connection of MUM-PSV
- Mediana pump
- Implement plumbing installation on-site with local company

Vào ngày 6 tháng 11 năm 2024, các hình tại tại đã được thực hiện theo lịch trình đã phác họa tại nhà chủ cùng sự Phối hợp với hai đội của công ty Abokiv WLO và TU Dortmund. Công việc về cấu hình máy và lắp đặt đã hoàn thành vào đầu tháng 12 và được vận chuyển đến Việt Nam để sẵn sàng vận hành tại nhà vào giữa tháng 1. Lắp đặt tại Corbett từ giữa tháng 2 năm 2025.

Những SUA / WLO Haven phải xem xét các công việc sau tại chỗ:

- Thảm cao su 10 mm làm lớp bảo vệ sàn, chống ồn và cách âm
- Kéo nối nguồn điện 33A/400V
- Lắp đặt thêm hệ thống thông gió
- Lắp đặt webcam để đọc dữ liệu trên màn hình hoặc làm rõ dịch vụ với WLO Haven để đọc dữ liệu.
- Lắp đặt kết nối MUM-PSV tại chỗ
- Lắp đặt bơm WWS/BMU
- Thực hiện lắp đặt công trình lắp đặt hệ thống ống nước tại chỗ với công ty địa phương

1x WWS Smart Pump to pump service water to irrigation system
 1x Máy bơm thông, máy WWS để bơm nước phân vụ cho hệ thống tưới nước

1x Dometic WWS PUR capacity 2,25m³
 1.000x 1.800 mm
 1x Bể lọc nước, được lọc 2,25 m³
 1.000 x 1.500 x 1.800 mm

1x Filter mesh unit for rain, grey and black water, nước xám và nước đen
 1x Bể lọc nước mưa, nước xám và nước đen

1x 1000L BIC water tank to collect grey and black water from building if existing pipes / DN 110 (90)
 1x Bể chứa nước BIC 1000L để thu gom nước xám và đen từ tòa nhà (4 ống hiện có / DN 110/90)

1x 1000L BIC water tank to store the ASU/LPT & substrate for irrigation
 1x Bể chứa nước BIC 1000 L để chứa nước BIC lọc - pH để tưới nước

1x DN 110 Exhaust to natural ventilation
 1x Ống DN 110 xả để thông gió tự động

Water processing: ASU / WLO / D-05/02

ALL MEASURES MUST BE DOUBLE CHECKED BY MANUFACTURER, SUPPLIER, SUBCONTRACTOR

SUA - Smart Urban Areas
 Trier 12

67EX0001A

TU Dortmund University
 Campus South, 08 St. Paul Platz
 August-Schmidt-Allee 10
 44227 Dortmund
 Germany
 www.sua-online.de

WLO SE
 Wlopp 1
 44229 Dortmund
 Germany
 www.wlo.com

ABOKIV Group GmbH
 Fiedlerstr. 36
 10117 Berlin
 Germany
 www.abokiv.com

CD TESTBED_02

Water Concept D-04 Update 2

A.09.3

DRAFT

F E D C B A

08.11.2024
 01.08.2024
 01.08.2024
 10.08.2024

WLO / Abokiv green painted wall
 Tường sơn xanh WLO / Abokiv

2x grey water pipe from building
 2x ống nước xám từ tòa nhà

2x black water pipe from building
 2x ống nước đen từ tòa nhà

400 Voltage Power Supply Access
 Nguồn điện 400 Volt Truy cập

POCC - Fire Fighting System
 POCC - Hệ thống chữa cháy

WLO / Abokiv:
 Water được tái sử dụng và được lọc sạch để sử dụng cho hệ thống tưới nước tự động. Nước này được lưu trữ trong bể chứa nước sạch và được trộn với nước mưa trong các bể chứa nước sạch. Nước này sau đó được sử dụng cho hệ thống tưới nước tự động.

Abokiv chọn ASU/LPT về phía WLO/Haven ở trên công trường. Một cấu trúc khung thép đã được lắp đặt và sẵn sàng để lắp đặt hệ thống tưới nước phân vụ.

80 lít nước mưa trên mỗi mét vuông hàng giờ để đóng thành bồn là ASU/LPT trên sân thượng. ASU/LPT có thể hoạt động 24 giờ.

System Information:

- linear arrangement
- direct to all 4 waste water pipes of building
- direct access to exit
- direct access for maintenance
- direct access to power supply
- direct access to natural ventilation (exhaust)

Thông tin hệ thống:

- bố trí tuyến tính
- trực tiếp đến tất cả 4 đường ống nước thải của tòa nhà
- tiếp cận trực tiếp đến lối ra
- tiếp cận trực tiếp để bảo trì
- tiếp cận trực tiếp đến nguồn điện
- tiếp cận trực tiếp để thông gió tự nhiên (xả)

Water Cycle - Vòng tuần hoàn nước

Water system and cycle architecture TestBed_02
 Kiến trúc hệ thống và chu trình nước: TestBed_02

10 mm rubber for noise and vibration insulation and as cover on the ASU/LPT
 Cao su 10 mm để cách âm, cách rung và làm lớp phủ trên sân thượng

Service water tank 1000L
 Bể nước phân vụ 1000L

Detail D-05
 Basement. Area for water treatment, rain water collection and re-distribution.
 Tầng hầm. Khu vực xử lý nước, thu gom và phân phối lại nước mưa.

Detail D-06
 Terrace down the ramp.
 Khu vực xuống dốc.

2 ton pallet filter rental / Cho thuê xe nâng pallet 2T
<https://thomaybenhan.com.vn/cho-thue-xe-nang-pallet-2-ton/>

2 ton pallet filter rental / Cho thuê xe nâng pallet 2T
<https://thomaybenhan.com.vn/cho-thue-xe-nang-pallet-2-ton/>

Current dimensions on site for water treatment unit
 Kích thước hiện tại tại chỗ cho đơn vị xử lý nước

Back alley width approx. 2.0m
 Chiều rộng hẻm sau khoảng 2.0m

ALL MEASURES MUST BE DOUBLE CHECKED BY MANUFACTURER, SUPPLIER, SUBCONTRACTOR

SUA - Smart Urban Areas
 Trier 12

67EX0001A

TU Dortmund University
 Campus South, 08 St. Paul Platz
 August-Schmidt-Allee 10
 44227 Dortmund
 Germany
 www.sua-online.de

WLO SE
 Wlopp 1
 44229 Dortmund
 Germany
 www.wlo.com

ABOKIV Group GmbH
 Fiedlerstr. 36
 10117 Berlin
 Germany
 www.abokiv.com

CD TESTBED_02

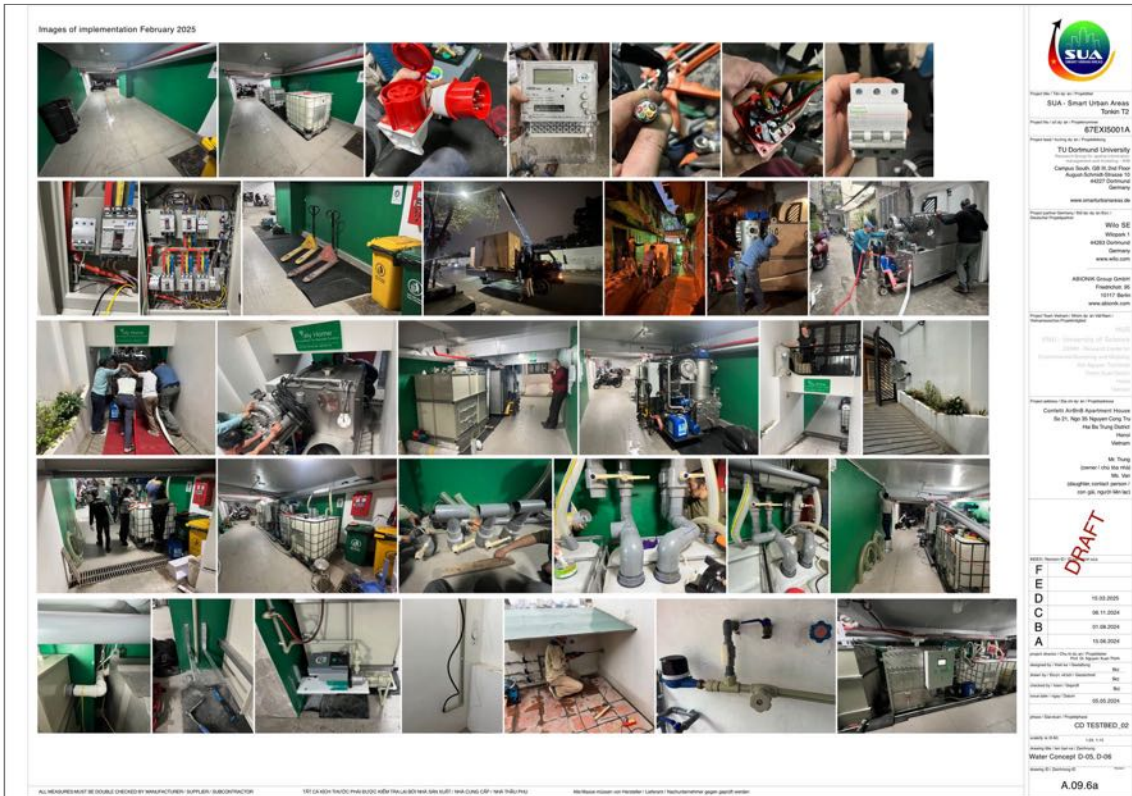
Water Concept D-05, D-06 Update

A.09.6

DRAFT

F E D C B A

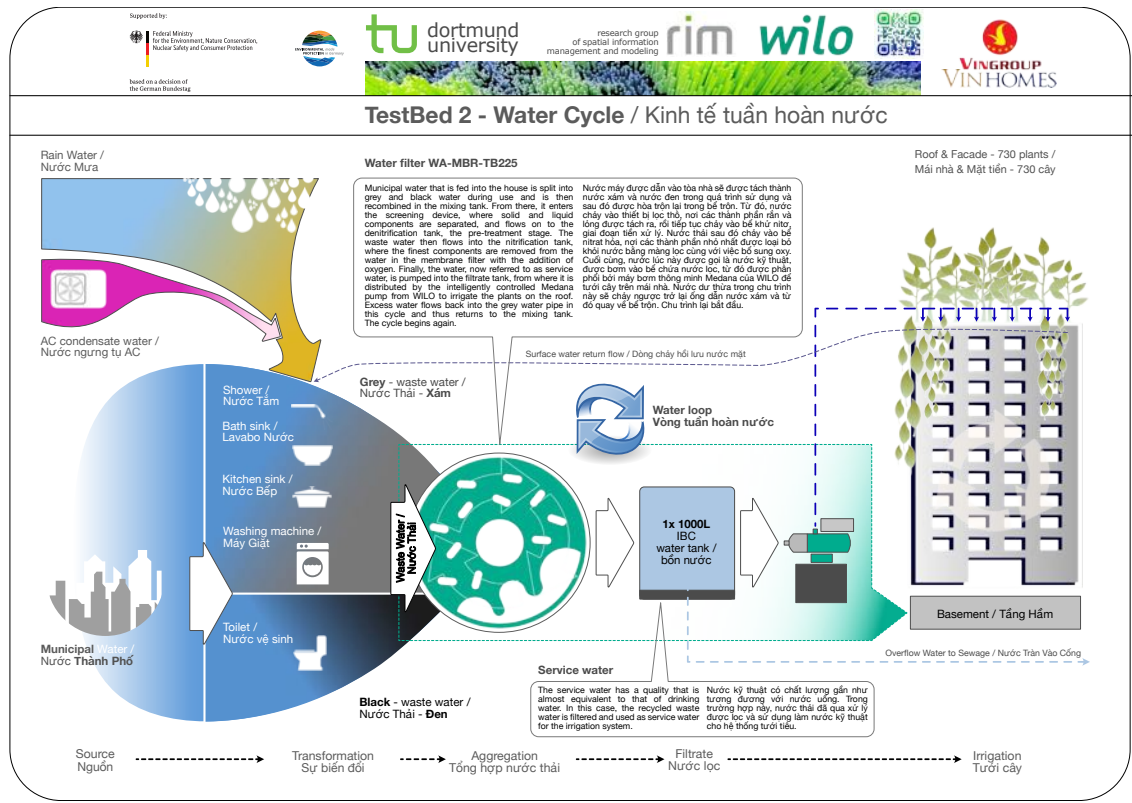
08.11.2024
 01.08.2024
 01.08.2024
 10.08.2024



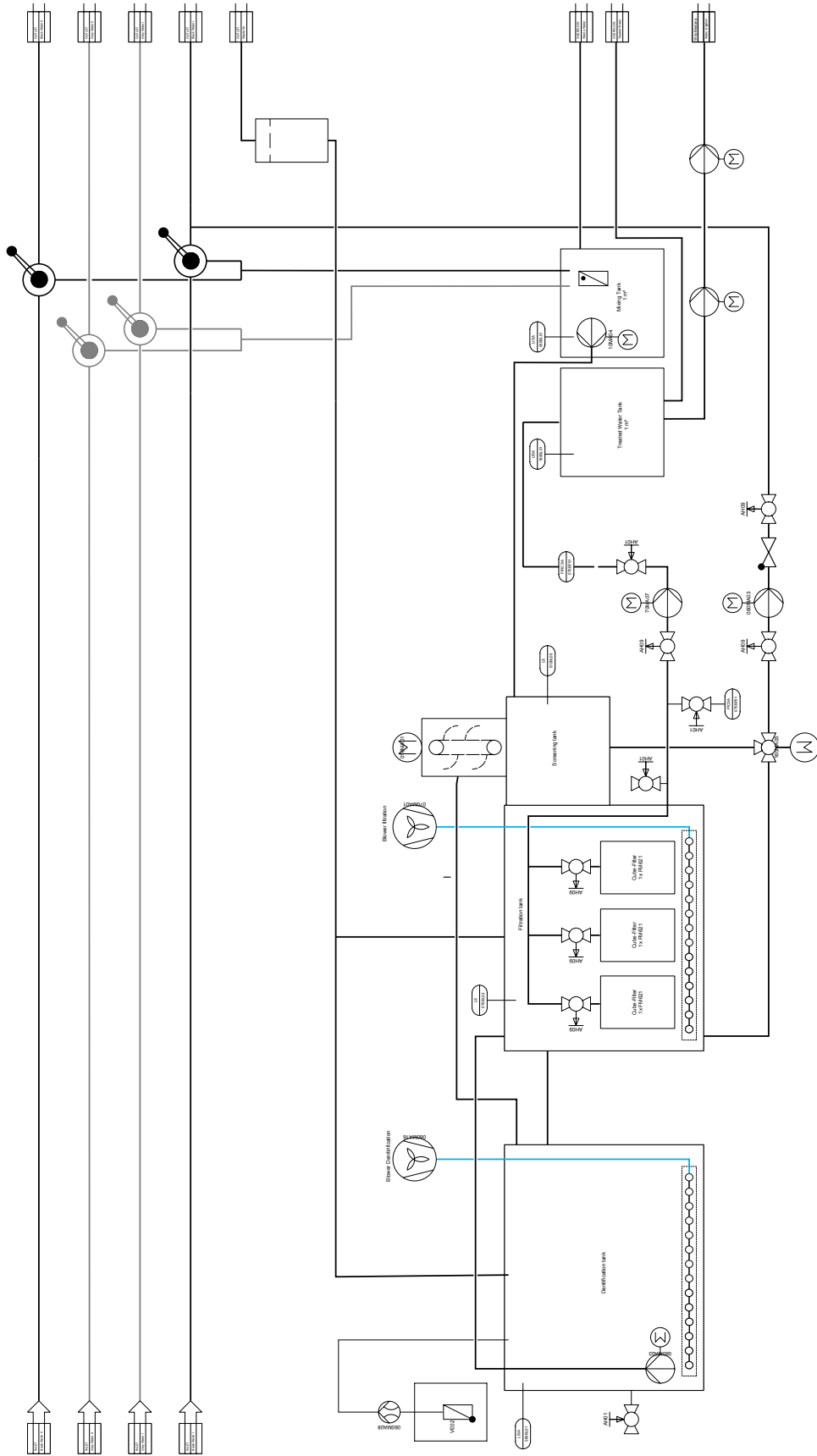
SUA
 Smart Urban
 TU Dortmund University
 67EX1001A
 Wilo SE
 48129 Dortmund
 www.wilo.com
 ABBECON Group GmbH
 48129 Dortmund
 www.abbecon.com

CD TESTBED_02


A.09.6a



Appendix B.3.2: RuL Schemata of WA-MBR-TB225



Appendix B.3.3a: Quality Certificate of Lobby Water vs. Regulation 1

VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY				
		INSTITUTE OF CHEMISTRY <i>Department of Inorganic - Physical Chemistry, 18 Hoang Quoc Viet Street, Nghia Do Ward, Ha Noi, VN</i> Tel/Fax: 024.38362968		
TEST RESULT				
Customer:	TU Dortmund University			
Address:	August-Schmidt-Str.10,44227 Dortmund, Germany			
Date of receiving:	17.06.2025			
Name of sample:	Mẫu nước từ hệ thống nước tòa nhà (From the lobby lavabo)			
No.	Parameter	Unit	Result	QCVN 01-1:2018/BYT
1	Color	TCU	< 1	15
2	Odor, taste	-	No odor	No odor and strange taste
3	Turbidity	NTU	< 1,0	2,0
4	pH	-	8,21	6,0 - 8,5
5	Free Chlorine	mg/L	< 0,01	0,2 - 1,0
6	Hardness	mg/L	100,0	300
7	TDS	mg/L	119,7	1000
8	Al (Aluminium)	mg/L	0,011	0,2
9	NH ₄ ⁺ (Ammonium)	mg/L	0,02	0,3
10	Sb (Antimony)	mg/L	< 0,001	0,02
11	As (Arsenic)	mg/L	0,0006	0,01
12	Ba (Barium)	mg/L	0,0018	0,7
13	B (Boron)	mg/L	0,001	0,3
14	Cd (Cadmium)	mg/L	< 0,0001	0,003
15	Cl ⁻ (Chloride)	mg/L	8,51	250
16	Cr (Chromium)	mg/L	0,0012	0,05
17	Cu (Copper)	mg/L	0,0013	1,0
18	CN ⁻ (Cyanide)	mg/L	< 0,001	0,05
<p>Note: Sample name written according to customer information; The results are only valid for analytical sample sent by the customer; Resolve the question within 05 business days of receiving the result.</p>				

Appendix B.3.3b: Quality Certificate of Lobby Water vs. Regulation 2



VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF CHEMISTRY

Department of Inorganic - Physical Chemistry, 18 Hoang Quoc Viet Street, Nghia Do Ward, Ha Noi, VN

Tel/Fax: 024.38362968

19	F ⁻ (Fluoride)	mg/L	< 0,01	1,5
20	H ₂ S (Hydrogen sulfide)	mg/L	< 0,01	0,05
21	Fe (Iron)	mg/L	0,0014	0,3
22	Pb (Lead)	mg/L	< 0,0001	0,01
23	Mn (Manganese)	mg/L	0,0108	0,1
24	Hg (Mercury)	mg/L	Not detected	0,001
25	Ni (Nickel)	mg/L	< 0,001	0,07
26	NO ₃ ⁻ (Nitrate)	mg/L	1,373	2
27	NO ₂ ⁻ (Nitrite)	mg/L	0,014	0,05
28	Se (Selenium)	mg/L	0,0018	0,01
29	Na (Sodium)	mg/L	0,154	200
30	SO ₄ ⁻ (Sulfate)	mg/L	8,18	250
31	Zn (Zinc)	mg/L	0,0016	2,0
32	Permanganate Index	mg/L	0,1	2,0
33	Total Coliform	CFU/100mL	0	< 1
34	E.coli	CFU/100mL	0	< 3
35	Staphylococcus aureus	CFU/100mL	0	< 1
36	Pseudomonas aeruginosa	CFU/100mL	6,3x10 ¹	< 1

Note: QCVN 01-1:2018/BYT : National technical regulation on domestic water quality

Ha Noi , July 8 2025

Deputy Head of Lab

INSTITUTE OF CHEMISTRY

MSc. Ta Thuy Nguyen

Note: Sample name written according to customer information;
The results are only valid for analytical sample sent by the customer;
Resolve the question within 05 business days of receiving the result.

Appendix B.3.3c: Quality Certificate of Filtrate vs. Regulation 1



VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF CHEMISTRY

Department of Inorganic - Physical Chemistry, 18 Hoang Quoc Viet Street, Nghia Do Ward, Ha Noi, VN

Tel/Fax: 024.38362968

TEST RESULT

Customer: TU Dortmund University
Address: August-Schmidt-Str.10,44227 Dortmund, Germany
Date of receiving: 17.06.2025
Name of sample: Mẫu nước từ bể lọc (filtrate tank)

No.	Parameter	Unit	Result	QCVN 01-1:2018/BYT
1	Color	TCU	36	15
2	Odor, taste	-	No odor	No odor and strange taste
3	Turbidity	NTU	< 1	2,0
4	pH	-	6,55	6,0 - 8,5
5	Free Chlorine	mg/L	< 0,01	0,2 - 1,0
6	Hardness	mg/L	180,0	300
7	TDS	mg/L	977,0	1000
8	Al (Aluminium)	mg/L	0,0084	0,2
9	NH ₄ ⁺ (Ammonium)	mg/L	7,211	0,3
10	Sb (Antimony)	mg/L	< 0,001	0,02
11	As (Arsenic)	mg/L	0,0004	0,01
12	Ba (Barium)	mg/L	0,0005	0,7
13	B (Boron)	mg/L	0,001	0,3
14	Cd (Cadmium)	mg/L	< 0,0001	0,003
15	Cl ⁻ (Chloride)	mg/L	127,62	250
16	Cr (Chromium)	mg/L	0,0005	0,05
17	Cu (Copper)	mg/L	0,0024	1,0
18	CN ⁻ (Cyanide)	mg/L	< 0,001	0,05

Note: Sample name written according to customer information;
 The results are only valid for analytical sample sent by the customer;
 Resolve the question within 05 business days of receiving the result.

Appendix B.3.3d: Quality Certificate of Filtrate Water vs. Regulation 2



VIETNAM ACADEMY OF SCIENCE AND TECHNOLOGY

INSTITUTE OF CHEMISTRY

Department of Inorganic - Physical Chemistry, 18 Hoang Quoc Viet Street, Nghia Do Ward, Ha Noi, VN

Tel/Fax: 024.38362968

19	F ⁻ (Fluoride)	mg/L	< 0,01	1,5
20	H ₂ S (Hydrogen sulfide)	mg/L	< 0,01	0,05
21	Fe (Iron)	mg/L	0,0013	0,3
22	Pb (Lead)	mg/L	0,0002	0,01
23	Mn (Manganese)	mg/L	0,0083	0,1
24	Hg (Mercury)	mg/L	Not detected	0,001
25	Ni (Nickel)	mg/L	< 0,001	0,07
26	NO ₃ ⁻ (Nitrate)	mg/L	31,642	2
27	NO ₂ ⁻ (Nitrite)	mg/L	0,340	0,05
28	Se (Selenium)	mg/L	0,0019	0,01
29	Na (Sodium)	mg/L	0,006	200
30	SO ₄ ⁻ (Sulfate)	mg/L	77,82	250
31	Zn (Zinc)	mg/L	0,008	2,0
32	Permanganate Index	mg/L	6,2	2,0
33	Total Coliform	CFU/100mL	1	< 1
34	E.coli	CFU/100mL	0	< 3
35	Staphylococcus aureus	CFU/100mL	0	< 1
36	Pseudomonas aeruginosa	CFU/100mL	1,1x10 ²	< 1

Note: QCVN 01-1:2018/BYT : National technical regulation on domestic water quality

Ha Noi , July 8 2025

Deputy Head of Lab

INSTITUTE OF CHEMISTRY

MSc. Ta Thuy Nguyen

Note: Sample name written according to customer information;
The results are only valid for analytical sample sent by the customer;
Resolve the question within 05 business days of receiving the result.

Appendix C.1: Greening Parkdeck 4

Building on a video scenario for Parking Deck Zone 4, which was produced prior to the interventions at Tonkin 2 and illustrated the potential of unused areas on and around buildings through animation, the local partner requested a detailed explanation of the greening concept for Parking Deck Zone 4. In response, recommendation documents were prepared which, through text and images based on 3D models, highlighted the areas and their potential. The following document and instructions provide information about how and where to apply greening and water storage for the local partner Vinhomes for further integration.



Greening recommendations

Dear Vinhomes,

We appreciate your step into greening buildings for valuable operations and support you with some recommendations for greening Parkdeck Zone 3 + 4 attached down below for your improvements.

Both buildings are in many ways similar in their construction and building quality besides purposes. Both buildings are capable of carrying green on the roof top rather than purely grey tiles that absorb more solar radiation that impacts the inner climate and room temperature. The buildings are made for parking with ground floor retail areas and top floor office spaces. Those spaces are exposed to the solar heat gain and faces high operational cost for cooling through air conditioning. They often lack



building quality standards especially at the threshold for glass doors between indoor and outdoor transitions, water leaks indoors. The advantage of the vast roof space especially at Parkdeck Zone 3 is the emptiness that can be transitioned into a roof top garden and park for the inhabitants of Vinhomes Smart City. A safe location and destination for parents and grand parents to relax, play and revive after a long day with their grand children and children. The ultimate concept is to understand

those spaces as regained from construction for the better and well being of the community. Opposite the road Parkdeck Zone 4 faces other opportunities that can help to green the building, lowering the energy consumption, improve the office spaces and in some ways the shopping experience itself. On the 10th floor there is found a courtyard not in use yet. Some doors lead to that open space that provides very good conditions for a green escape at lunch time or after work get together. Opening the exterior walls with room high windows to get day light into the deep floor plans would increase work quality and performance besides advantages in renting these office spaces. The inner courtyard offers the possibility of a recreational island within the Zone 4 parking deck and especially for the operators of the office space. Employees can also use this space during their lunch break and in the afternoon hours to relax, find inspiration and, above all, recharge their batteries for work. The spaciousness of the courtyard also offers the opportunity to create a park with raised beds and seating. This would create attractive areas with lush greenery, especially in a "forest-like" design, which would ensure a high level of well-being. The north-east orientation of the courtyard offers very good conditions in the morning and at lunchtime for the plants to develop under protection. Consideration could be given to designing the façade with greenery, which would further enhance the quality of the space.

In the following, reference is made to the plans sent, which only partially depict the Zone 4 parking deck building. The plan drawings indicate areas that can be used for intensive greening. Intensive greening is referred to as a substrate structure from a height of over 200 mm. Sectional drawings are used to show how such measures can be implemented. These should be adapted to the local situation. Landscape planners and builders can help you make the right choice of plants. We are happy to support you with the system structure of the soil, as we combine experience from Vietnam with knowledge of the Miyawaki method from Japan to create a "forest-like" situation that ensures a high level of biodiversity and strong shading. The tips on using rainwater can also be applied to other projects. The SUA project is pursuing these goals and applying this technology to TestBed_02, where more details and data will be available next year. According to current knowledge, savings of up to 80% of water can be achieved with the system of collecting and filtering rainwater, grey water and waste water if

the system is designed and applied holistically. This requires early conceptualisation in planning and changes in the general handling of MEP indicators. A step in the planning process that can be considered for new building and urban areas developments. In this retrofit ensemble, we recommend at least the use of rainwater, which is also used to irrigate the plants.

On the following pages, we share with you our findings from the current SUA project and further thoughts, which should be considered and examined as a whole.

The plant selection we propose concerns TestBed_01 and TestBed_02, where we can say with certainty that this system works. However, both TestBeds should be considered as "test plants", organized and designed in such a way that we can collect reliable data with sensors in order to realize and, above all, optimize them in later applications. The greater the diversity of plants, the greater the resilience of the green space and the greater the biodiversity but on the other hand the more difficult it is to collect data. However, this will not be necessary on the Zone 4 parking deck, as we can already work and expand on the experience we have gained in the SUA project.

Good Luck!



04.11.24
Page 1 of 7

tu dortmund university | rim wilo | VINHGROUP VINHOMES

Green spaces

Courtyard on Floor 10. Entire area is able to reshape into a green park/garden. Plants and trees up to 5m can be planted. Access to this space for public and office workers is possible.

All Loggias can be shaped into gardens by high and hanging plant beds.

On all Loggias high and hanging plant beds can be placed, there is enough space available. Using the balustrade to hang planters while put on the ground planters up to 800 mm and fill with soil/humus. A lush green is feasible.

TANG10
Parkdeck Zone 4

04.11.24 Page 2 of 7

tu dortmund university | rim wilo | VINHGROUP VINHOMES

Both roof top areas above the ramps are able to use conveniently for greening purposes.

All squared spaces are feasible while double checking technical equipment stored, pipes laid on roof and especially the exhaust fans and direction due the fact that most air out blown is too warm till hot and hinders plants to grow. Check carefully the locations and size and especially the piping/ducts. Apart from that any green space on the roof top supports aspects of shading and cooling besides increasing birds species. In addition to that the diversity of the planted green supports the biodiversity and resilience of the green for the long run of operation.

These tiles reaching >60 degrees Celsius in summer time, paving joints show breaks, construction damages occur. The green helps partially reducing such side effects.

*green squares and circles resemble schematic meaning

TUM
Parkdeck Zone 4

04.11.24 Page 3 of 7

tu dortmund university | rim wilo | VINHOMES

The facade area of **Parkdeck Zone 4** spans approx. **16.000 - 18.000 square meter** of green surface uncovered. A surface that is exposed to solar radiation to the South and West and therefore suitable for shading appliances.

The plant Cuc Tan An Do grows up to 3 meters per year, comparable to the height of one floor. If these plants prepared on each floor, a green facade is ready within one year. If planted on every second floor or randomly arranged due a detailed design concept the facade will be covering the building after two years.

The hanging container at TestBed_02 reaching around 15kg for two plants. Cuc Tan An Do needs lots of soil, therefore we recommend plant containers of 300x300 mm and 500-600 mm in length. All plants require a decent storm construction and safety. The gap of hanging curtain to the exterior wall with 500-600 mm keeps distance and provides vertical ventilation as seen on the detail section to the right. There are different options how to hang the containers at the facade. The one shown on the right side sits on top of the rail wall, provides loads directly into the wall. Another option is hanging in front of the wall. Both is feasible. The plant names mentioned on the second right are also feasible for roof plantation but not suitable for a green curtain. Stand alone as heavy facade the solution is feasible, not as retrofit as for building Parkdeck Zone 4.

Random green containers with 'forest' on roof top.

On most sides of the building hanging green can be applied to the facade.

On 6th floor there might be another courtyard that is able to carry and provide space for a 'little' garden.

04.11.24 Page 4 of 7

tu dortmund university | rim wilo | VINHOMES

All areas that are 'green' marked are optional and feasible to use for greening. Nevertheless placing green should be done in accordance with existing piping/ducting/exhaust vents.

If access for public is desired, required and/or possible, we recommend creating a walking path, rest areas and sitting benches. For instance the courtyard would be a great area to rest at lunch time.

The areas on the roof top between technical equipment we recommend to use as carbon sinks, biodiversity and untouched bird breeding spaces.

*green squares resemble schematic meaning

04.11.24 Page 5 of 7

On this page some technical details show solutions for roof top and facade green as sections. The hand sketch on the right side gives you information about a suitable way for the 10th floor including the plant species we using for TestBed_01 at Yen Lang road and TestBed_02 on Nguyen Cong Tru street. Due the wider spaces and areas on ParkDeck Zone 4 we recommend furthermore to extend the plant variations using domestic (local) plants. All plants arranged in a dense mix provide a good shading of the building surface and plant resilience. The roof top plant containers or beds require less maintenance than the facade planters. We recommend the intensive green with a minimum of 600mm thickness of soil layer, a combination made from 1/3 drainage layer and 2/3 soil layer. As higher the total thickness the ratio can be changed to 1/5 drainage and 4/5 soil layer. The drainage layer need to adjust to the situations in accordance with construction. Avoid standing water or wet roots. Some products are available at VGBC platform. Besides that landscapers can support you. We using the Miyawaki-method for fast growing and natural density for green.

The majority of hanging plants **Cay Tan An Do** can be combined with the creeper plant **Cay Tat Ke (cây tác kê)**. The creeper climbs up at the columns, the hanging plants just hang in distance of approx. 500mm to the facade.

Hanging metal planters in approx. 300x300 mm and variable length for the Cay Tan An Do plants. Keep distance to the exterior wall.

Standing plant container made of bricks or even thinner material, filled with a filter fabric, a drainage layer and a thick soil layer. Variations of plants possible.

Plant recommendation i.e.:
 - Butterfly Palm, **Cay Cau Lua Vang** (Cây Cau Vàng)
 - Common Fern, **Cay Duong Xi** (Ngành Dương xỉ)
 - Blood Clamshell (Purple Shellfish), **Cay So Huyet** (Cây số huyết)
 ...etc.

The higher the variations the higher the diversity and resilience of the green!

Technical drawings for Tonkin scenarios. Those information can be updated and applied to both Parkdecks 3 + 4.

04.11.24 Page 6 of 7

Rain water harvesting

The roof top area of **ParkDeck Zone 4** spans approx. **10.500 square meter** of surface uncovered besides some before mentioned technical equipment (~10%) for the parking garage, office space and shopping mall in 1st and 2nd floor.

A stormy and rainy day in Hanoi provides 200-250 mm of precipitation. Counted the roof top surface of ~9.000 square meters and multiply by 1.600 mm precipitation (= 1,60 cubic meter water) annually, the down pipes need to handle **14.400 litres** of rain water over the year. Water that can be used for plant irrigation and reducing fresh water usage. This water should be stored in water tanks. A suitable location is within the ramps or on the rear side of the building at ground level or in basement.

With fully integrated water systems and green scenario thinking all technical equipment for downfalls can be optimised towards smaller dimensions and amount of quantity due the fact that the plants store water in the soil on the roof top. The cycle of water is a closed cycle if using rain, grey and black water from the building itself and feed the irrigation system again.

Down pour pipes to collect water. Carefully check location.

Gutter that is aligned around the building to gather the rain water and avoid flooding of the roof.

Water cycle if fully integrated in the design and build.

Water Cycle - Vòng tuần hoàn nước

TUM
Parkdeck Zone 4

04.11.24 Page 7 of 7

Appendix C.2: Construction Materials and Building Envelope

The following recommendations to the local partner on building materials and construction methods incorporate detailed considerations and findings from this research. That encourages the partner to adopt holistic aspects in the development of urban districts in order to plan and build more cost-effectively, efficiently, and with higher quality. The following images provide information about building envelope recommendations, construction methods and construction materials.



Material recommendations

Dear Vinhomes,

As mentioned in the Green recommendations we appreciate your endeavours towards sustainable buildings.

At our Zoom meeting on October 28, 2024, we discussed the possible use of new materials and technologies for the construction of buildings. In this case, it is important to look at buildings holistically, i.e. not just the cost side, but also the building envelope and infrastructure, because there is potential there. Everything plays into each other and together, and furthermore the changing climate in Hanoi also has a strong influence on the future and, above all, the operation and maintenance of every building.

The **building envelope** absorbs energy and tries to release it again at night, which can usually be recognized by heat radiation or reflection. The



climate therefore has a strong influence on building materials, weathering and their durability. The infrastructure is subordinated to this order and binds or adapts to the requirements. The higher the quality of the building envelope, the more efficient the technical building equipment.

For these reasons, it is important that the building envelope is considered as a whole when constructing a prototype house (i.e. villa). All components

of the building envelope, such as windows, doors, masonry, openings, balconies and plaster must have the same thermal properties. Today's building culture in Vietnam understands the wall of the high-rise or building as a flat opening that must be closed so that no weather influences affect the interior. Walls are therefore installed between concrete slabs and in sometimes varying thicknesses, which often leads to thermal bridges. However, these should be avoided as they lead to a weakening of the building envelope and performance and therefore to higher costs when operating the building, e.g. energy costs for air conditioning systems. In addition to that they can cause moisture problems. This manifests itself in flat grey-black mildew stains on the wall surfaces. It often starts in the less well-ventilated bathrooms, but can also quickly manifest itself as a negative event on the weather sides of the building. This should be prevented as it affects the health of the occupant and can only be combated with chemicals (chlorine or ammonia).

Two examples: Imagine a raincoat with holes in it. You get wet even though you don't want to. Or a warm sweatshirt that is supposed to keep you warm in the cold season, but the sleeves are missing. In terms of buildings, these are damaged building envelopes where energy, heat and costs are lost.

The global construction industry is responsible for 40% of CO2 emissions. Urban areas are therefore important to consider, as they create living spaces on the one hand and use a lot of materials on the other. Concrete is one of the oldest and mostly used material nowadays and will last as important building material until current developments in science and industry enable solutions for regenerative construction. These include renewable raw materials such as wood and bamboo, which can be used to transform cities into artificial carbon sinks (ACS) through circularity. The idea behind the circular construction is to use resources sparingly and repeatedly, even after their original purpose has expired. You can imagine hybrid cities combining traditional building techniques with modern building materials. It will realistically remain a mixture.

It would be wrong to think of one building material without the other, hence the focus here on the following two materials, **reinforced concrete** and **masonry**. In addition, windows and doors are another very important element for the building envelope, but they are made of several materials. Due to their complexity, we will report more on this at another time. With

the two aforementioned materials, Vinhomes is able to build faster, more efficiently and to a higher quality than before. The SUA project is focusing on these properties in the test building and will try to present them holistically in the coming year.

Your engineers can obtain further information from the given web links to providers and technologies. Most pages are available in Vietnamese and/or English. If you have specific questions, you can contact us at any time.

Good luck.

05.11.24



Page 1 of 8



Concrete improvements

The technology of hollow core slabs is over a hundred years old and has entered new dimensions with the development of hollow bodies made from recycled materials 25-30 years ago, which have a number of advantages that should be considered.

The advantages arise with the use of hollow core slabs:

- Lightweight construction and therefore greater building rigidity
- 30-40% savings on raw materials such as concrete in the area of slab construction
- Higher spans for ceilings and slabs
- Less number of columns required
- Reducing material for pile foundation and general foundation

Well known companies are down below:

- The Inventor: www.bubbledeck.com
- The Newcomer: www.unidome.de
- The Local in Vietnam: <https://pc.vn/>

Other experienced suppliers are available in Vietnam by now. 2018/19 we once cooperate with a 'u-boot' system for a 25 storey mixed-use building in new CBD Hanoi. Resource savings by 34% were calculated at that time for that specific building. In the near future those "spacers" will be available for vertical building elements i.e. walls or pile foundation.

The different colors come from the recycled plastics that are processed.

Recesses are deliberately made in the area of the supports, i.e. the load transfer and reinforcing steel connectors.











<https://www.dalform.com/en/permanent-formwork-for-two-way-lightened-voided-slabs/>



<https://pc.vn/u-boot-concrete-giai-phap-huong-dan-cong-trinh-khinh-trong-kay-dung/>

Page 2 of 8

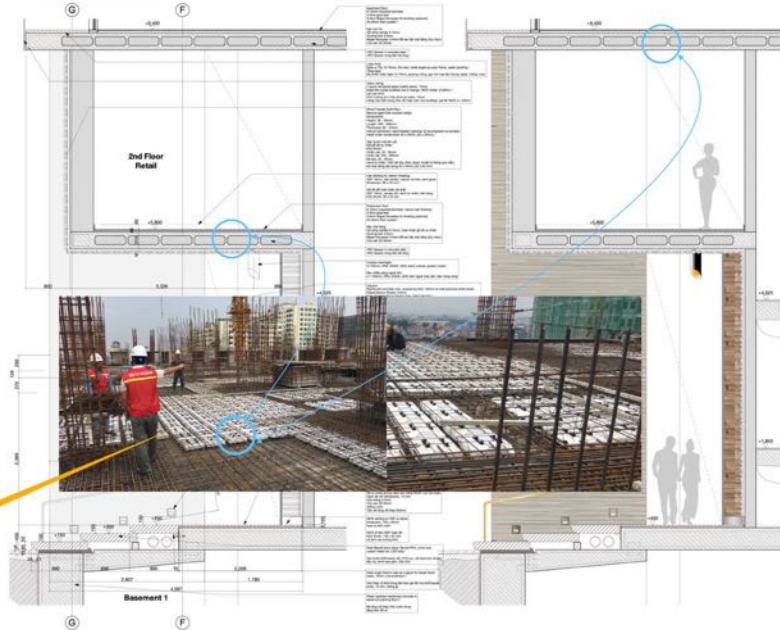


Concrete improvements

The example on the right shows a section of a high-rise building in which the "u-boot" system was used. The oval shapes in the middle of the concrete ceiling are clearly visible.

At the same time, a construction site in Hanoi was visited where this technology is being used in a high-rise residential building in order to gain a personal impression of the technology on site in addition to an intensive technical discussion with the workers responsible. The work processes and procedures are adapted to the technology. Some general contractors in the Hanoi area are familiar with this technology and can be consulted.

Recesses are usually found in the area of columns, stairwells and bathrooms, as this is where the load-bearing nodes and especially the steel connectors are located. The usual ceiling areas can be easily filled with the spacers, hence the common rule of thumb of 30-40% material savings in the concrete area.



Page 3 of 8

DIFFERENCE - SỰ KHÁC BIỆT - 1M²

DA GACH versus DA AAC

Total wall thickness 240mm

Total wall thickness 210mm

m2 (square meter) exterior wall

Description	Dimension mm	Weight	QTY	Unit Price	Price m2	Description	Dimension mm	Weight	QTY	Unit Price	Price m2	
Adobe brick stone sachets, with two holes	200 x 100 x 50	1,5 - 1,8kg	1 đ	1.200		Autoclaved aerated concrete AAC	600 x 200 x 200	19 kg	1 đ	30.000		
Cement joint roughly	15-20 mm					Cement joint roughly	3 mm					
Cement plaster	15 (in two layers)					Cement plaster	5-5 (in one layer)					
Thermal value	0,81 W/mK					Thermal value	0,18 W/mK					
CALCULATION ON 1SQM						CALCULATION ON 1SQM						
Bricks		187,20 kg	125	đ	150.000	AAC		118	8,3	đ	250.000	
Cement joint (no plaster)		25kg	Set	đ	140.000	Cement joint (no plaster)		2kg	Set	đ	40.000	
Time			4	hrs	đ	160.000	Time		0,5	hrs	đ	30.000
SUM		212 kg			đ 450.000	SUM		136 kg			đ 320.000	

This table shows the specifications of both walls in comparison.

The numbers can be taken as reference but need an update to the pricing of nowadays.

Advantages to traditional brick:

- 30-40% less weight of the building
- 80-90% less mortar used for joints
- 8-times faster built than traditional
- Sound optimised
- Planar adhesive system (3mm)
- Reduced stone cut
- Higher thermal insulation while thinner
- No thermal bridges
- Reduced mould appearance

• Lotus / LEED certification safe

Cost advantages:

- A lighter building requires a thinner structural concrete framework and less pile foundation = less amount of concrete needed.
- A higher thermal insulated building requires smaller AC units = less weight on the building, less energy consumption.

05.11.24 Page 6 of 8

Observations at the construction site of Vinhomes Oceanpark 1 show that AAC4 100 mm is being used for the Masteri Waterfront condominiums. According to the EU DIN standard and QCVN 09:2013/BXC, the 100 mm stone is a classic interior material that is only used for room partitioning and has no load-bearing properties.


Suitable thermal insulation is provided by 200 mm AAC4 for external walls, especially for large glass walls and balconies/loggias.

Avoid mixing too many wall materials, especially traditional bricks and aerated concrete due to their properties. Brick is harder, while aerated concrete is softer and has a different expansion and fracture behavior. Sometimes it is necessary to divide the building into an above-ground and an underground construction to counteract rising damp from the subsoil.

From my visit to OceanPark, I know that you have done some material tests with aerated concrete before using the material. Our recommendation is to continue these tests and work with AAC. It is by far a cost-effective alternative to traditional brick and offers a viable solution for high-rise construction in Vietnam.

Thermal bridge = losing cool air = gaining solar radiation = cost deficit

05.11.24 Page 7 of 8




The schematic sketches on the right show the building envelope and how it can be optimized. Especially for high-rise buildings. This leads to a relatively seamless construction of the walls and "bands" the floors so that no thermal bridges are created. Compared to conventional exterior cement plaster, the plaster application is thinned from 15-30 mm to 3-5 mm while the interior plaster is thinned from 10-15 mm of mortar based to 3 mm thin plaster for AAC.

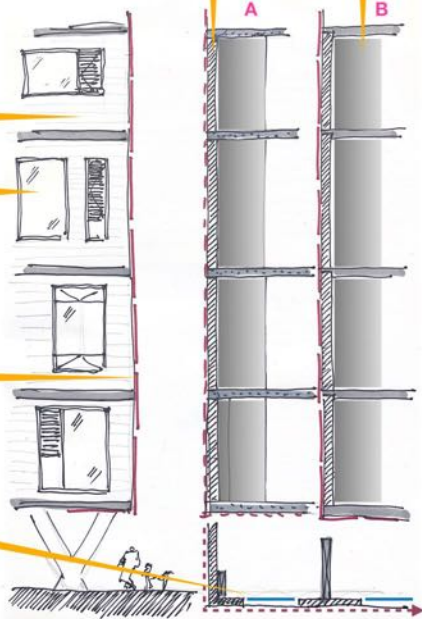
Arrange the windows where necessary to get the best daylight and align them accordingly. Floor-to-ceiling windows often suffocate small rooms behind the window, especially from an energy-efficient and thermal point of view.

If the building stands on the ground or a subterranean garage, the building envelope is below ground level and must be applied again separately horizontally at ground level to prevent rising damp from entering the masonry.

Taking this idea a step further leads to completely different, interesting and lucrative concepts that should be reconsidered for future developments. Especially in terms of integrating plants into the building (creation of carbon sinks), minimizing fears when parking in basement lots and promoting well-being in the residential area. More details in due course.



Example: The slabs are visible. All other vertical concrete wall elements are set back of 205 mm and give places for exterior wall material for higher thermal protection.



No wall (vertical element) column visible. The AAC wall material provides higher thermal insulation and protect unnecessary solar impact into the construction.

Random variations of windows possible.

The red line shows the building envelope outer barrier. In other words the outer skin.

Windows set on the inner site of the wall provides higher insulation = avoiding thermal bridge

200 mm Exterior wall (A)

205mm set back concrete column (B)

*schematic hand sketch gives an idea of concept

05.11.24
Page 8 of 8

Appendix C.3: Villa 2.0

In early 2025, the local partner requested the methodological integration of greening into a standard villa type in order to introduce new approaches within the planning department for otherwise standardised mass housing. The planning for large urban districts developed by the local partner offers the possibility of scaling up the ideas and findings of this research, with clear advantages for resource-efficient construction and water reuse. Such large-scale developments also allow for system-integrated circular economies that have not previously been planned or built. Based on the provided documents, the villa type was modelled in 3D, virtually greened, optimised in detail, and documented. Knowledge from this research on systemic-holistic design was incorporated, demonstrating how recycled water and greening can be combined. Small measures of this kind can have significant impact at the district level. In this case, more than 800 villas are planned, representing approximately 4,000 residents. With an average water consumption of 130 liters per person per day, this corresponds to 520,000 liters of water, of which 90% could be treated and reused.

It must also be noted that recommendations of this kind were often handled in the same manner as experienced throughout the project: communication media were not read or reflected upon, and established systems and products already available on the market were preferred due to their lower costs and long-standing acceptance.



Villa Xanh recommendations

Dear Vinhomes,

As in the two previous recommendations for sustainable and green buildings and building materials, here is the third recommendation for a typical villa at your request.

We have examined the plans you sent in PDF format in more detail, taken the model villa with the identifier M4-DL2 as an example and adapted suggestions to it. The villa was rebuilt in simplified form in CAD to illustrate the principles in more detail using the PDF plans and screenshots from augmented and virtual reality. These suggestions are to be considered by you and examined for real implementation.



We give these recommendations to you based on local construction experiences, approach and feasibility in Vietnam.

Building envelope:
The building envelope consists of 200 mm AAC blocks, glued in thin bed. Plastered on both sides with an approx. 5 mm layer for AAC blocks. The ceilings themselves can also be made of AAC panels or in reinforced concrete. For the reinforced concrete ceilings, we refer again to the material reducers, e.g. U-boot, which are available in Vietnam to reduce beams. Reinforced concrete columns in the building or as load-bearing elements on the stairs can be made slimmer or in thicknesses of 200 mm. Your engineers can fall back on standardised construction techniques.

The illustration on the left is the design you provided. The building envelope, consisting of conventional bricks and covered with cement plaster, is thermally charged during the day. The aim here is to use AAC bricks as an option. This material has better thermal properties, among other things. The advantages of your villa can be found in the flat roofs. Also an area that is solar loaded over the day that can be converted into green areas to protect the house from excessive thermal impact and thus reduce the energy consumption of air conditioning units. The flat terraces and balconies are converted into so called "oases" and provide cooler air and greater shade, thus reducing the surface area of the building envelope again.

Another advantage is the high-efficiency water pumps used today with energy consumption on demand and therefore energy efficient besides technical advantages. This eliminates the need for a water tank on the roof. We can distribute the water evenly throughout the house with i.e. a small WIL0 SE pressure-boosting pumps without the risk of a pressure loss.

In addition, there is the harvesting of rainwater and, in the event that wastewater is still to be used, a small service water filter system. This water can be used to irrigate the plants on the building and in the garden. The idea of the service water filter system, i.e. converting waste water of residential building into service water, can be implemented centrally for 100 or more buildings and, after filtration, can be fed back to the buildings as "free" water for irrigation in a sustainable manner or can be used from the management services as irrigation water for the green streets in this area.

The villa on the right shows the same floor plan as yours in a simplified or modernised design, but with greenery in decent places on the building.

Because the villas are mass-produced, they can be viewed as a system, especially with regard to the water filter unit. The greening can also, in a figurative sense, have a quantified positive effect on the settlement. The more surfaces in general are greened, the more shading there will be on the building walls and surfaces. This shading in turn ensures a cooler environment and the reduced use of air conditioners consumption results in lower heat output.

In short, the greenery, water circulation and a healthy building envelope create a cycle from an energetic perspective that Vinhomes can sustainably set as a standard for its ecological footprint.

Good luck!



29.01.25
Page 1 of 7

tu dortmund university | rim wilo | VINAGROUP VINHOMES

Introduction

Technical room (new):
 Instead of a green space, a room of 9 square meters with a green roof is created here. The following facilities are located in this room:
 1) Central rainwater collection tank and distribution pump.
 2) Pressure booster system for service water. (That eliminates the need for a water tank on the building's roof.)
 3) Optional: waste water filter system.
 4) Garden tool store.
 5) Pool water filtration and treatment system.
 6) On roof: optional, One AC outdoor split unit for all floors.

Villa and technical room attached to the rear of the building

29.01.25

Technical Room

Green market areas covered with domestic plants, creepers, trees, shrubs and bushes, depending on the landscape design.

Skip window on that wall. Add two more on wall facing pool.

MẶT BẰNG TẦNG 1

Page 2 of 7

tu dortmund university | rim wilo | VINAGROUP VINHOMES

Green spaces

Green on balconies and loggia

29.01.25

Green on both side of loggias and balconies supporting the natural cross ventilation.

Loggia and balconies:
 Up to 900 mm substrate in 2-3 layers inclusive drainage to avoid water logging. The soil substrate replaces insulation and protects building from solar radiation along with plants.
 Local / domestic plants necessary. Irrigation hoses optional, can be done by the home owner.

Plants recommended:
 1) Butterfly Palm, **Cây Cau Lua Vàng** (Cây Cau Vàng)
 2) Common Fern, **Cây Dương xỉ** (Ngành Dương xỉ)
 3) Blood Clamshell (Purple Shellfish), **Cây Sò Huyết** (Cây sò huyết)
 4) **Cúc Tân An Do** (hanging plants)

More flowery plants are welcome too and improves the visibility besides biodiversity as well as setting a personal touch.


MẶT BẰNG TẦNG 3

Page 3 of 7

tu dortmund university | rim wilo | VINHOMES

Green spaces

Loggia



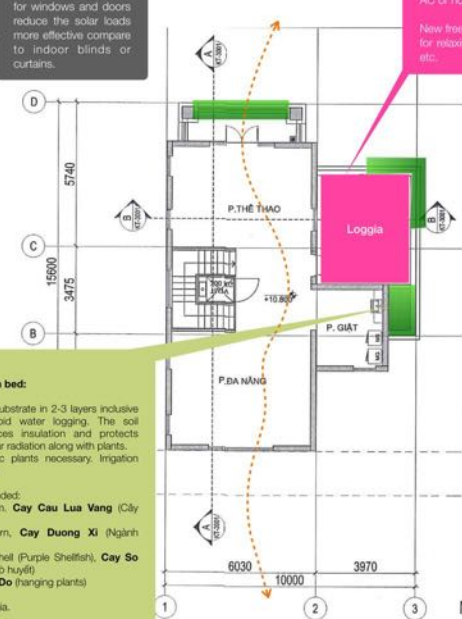
Outer shading blinds for windows and doors reduce the solar loads more effective compare to indoor blinds or curtains.

No water tank and solar collector any longer. Optional AC or not.
New free and shaded space i.e. for relaxing, dry clothing, dining etc.

Loggia and high bed:
Up to 900 mm substrate in 2-3 layers inclusive drainage to avoid water logging. The soil substrate replaces insulation and protects building from solar radiation along with plants. Local / domestic plants necessary. Irrigation hoses necessary.

Plants recommended:
1) Butterfly Palm, **Cay Cau Lua Vang** (Cây Cau Vàng)
2) Common Fern, **Cay Duong Xi** (Ngành Dương xỉ)
3) Blood Clamshell (Purple Shellfish), **Cay So Huyet** (Cây sò huyết)
4) **Cuc Tan An Do** (hanging plants)

Access from loggia.




MẶT BẰNG TẦNG 4
Page 4 of 7

tu dortmund university | rim wilo | VINHOMES

Green spaces

Perspective of the roof green



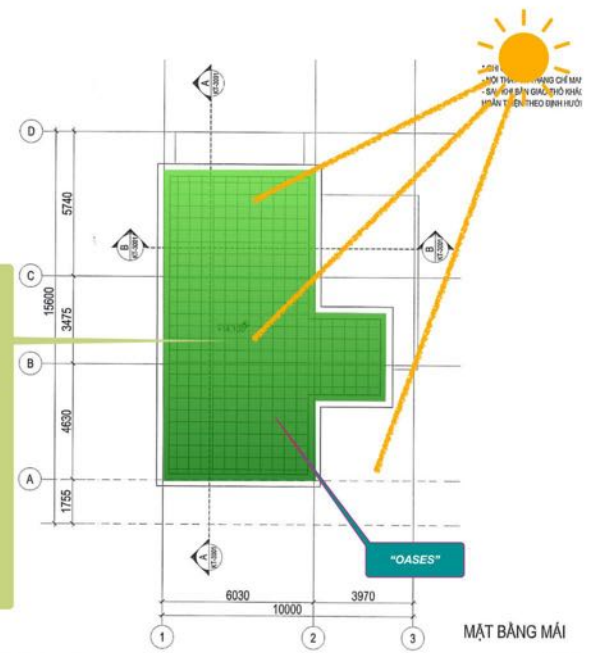
Outer shading blinds for windows and doors reduce the solar loads more effective compare to indoor blinds or curtains.

Roof, approx. 75 sqm:
Up to 500 mm substrate in 2-3 layers inclusive drainage to avoid water logging. The soil substrate replaces insulation and protects building from solar radiation along with plants. Local / domestic plants necessary. Irrigation hoses necessary. Solar collector possible.


Plants recommended:
1) Butterfly Palm, **Cay Cau Lua Vang** (Cây Cau Vàng)
2) Common Fern, **Cay Duong Xi** (Ngành Dương xỉ)
3) Blood Clamshell (Purple Shellfish), **Cay So Huyet** (Cây sò huyết)
4) **Cuc Tan An Do** (hanging plants)

The higher the variations the higher the diversity and resilience of the green!

Access via ladder from loggia.




MẶT BẰNG Mái
Page 5 of 7




Construction

Top view of 'Smart Green City'



3D section

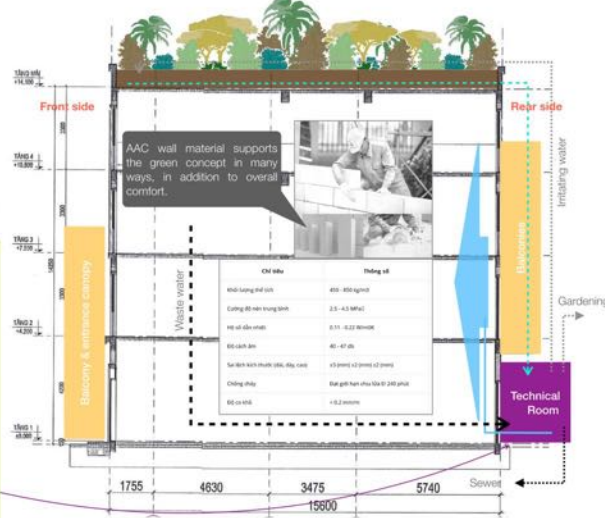


Smart Green City

The green potential on hundreds of flat roofs of villas M4-DL1 and M4-DL2 of this community results in an "elevated forest" - which not only cools through shading, but also ventilates the entire urban area more efficiently and mixes it with fresher air thanks to the enormous surface area. You can imagine the positive features for the residents, especially the overarching added value for people, nature and the building stock.

As already mentioned, collecting rainwater can help to irrigate the plants. The waste water mentioned above can also be centrally collected and filtered to support the irrigation system. Only one-off investments and maintenance are required here.

No valuable tap water would have to be used any longer.




Technical Room

Chiều dài		Chiều rộng	
M4-DL1 (m)	4.00	M4-DL2 (m)	4.00
M4-DL2 (m)	2.5	M4-DL1 (m)	2.5
M4-DL3 (m)	0.75	M4-DL4 (m)	0.75
M4-DL4 (m)	0.75	M4-DL3 (m)	0.75
M4-DL5 (m)	0.75	M4-DL6 (m)	0.75
M4-DL6 (m)	0.75	M4-DL5 (m)	0.75


AC on roof **Pool water filter** **Rainwater** **Booster pump**

- Swimming Pool
- Chlorinator
- Pump
- Sand filter
- Pool Chiller & Heat Pump



Equipment

Street and backyard view, Villas in a row



Conclusion:

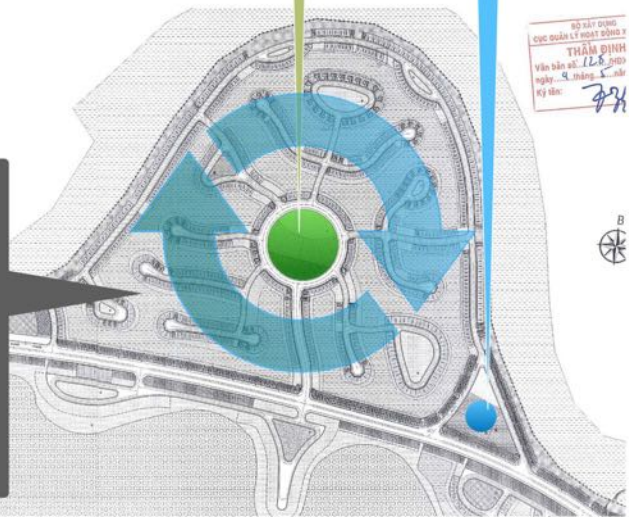
The section of the development shown here illustrates a conceptual idea that is primarily of strategic and sustainable importance. The basic idea is to make use of rainwater, to purify wastewater and use it for irrigation instead of municipal water, to optimise the materiality of buildings, and to optimise cooling efficiency with native plants to reduce the cooling load of air conditioning units.

A 'green' building is undeniable as a solitaire, but scaled up in the sum and on the scale of the settlement, intelligently transferred with the system potentials for water, it makes a statement that needs to be considered.

An example:

In each villa 4-6 people live with a water consumption of 140 l / day / ea. i.e. about 700 l / day. The collected water from approximately 800 villas is approximately 204,000 litres per year. The assumption is that we can recycle 80% of the waste water as irrigation for public parks, green areas and plants on the buildings, we are talking about a saving of approximately 163,200 litres per year. This is equivalent to 163,200 cubic metres of water. At the current price of about 15,000 VND / 0.6 USD / m³, this amounts to about 100,000 USD / year. In comparison, one cubic metre of tap water in Germany costs about 1.70 USD. This would translate into a saving of approximately 280,000 USD / year.

This is just a simple example that needs to be double checked. In addition the recommendations and values we have established, and the assumption that consumption prices will rise, now provide an opportunity to think about resilience.



Suggestion: Central circular forest with parkways for community

Suggestion: Mid size and housed waste water treatment unit that serves this 800 villa community with service water for irrigation and gardening.

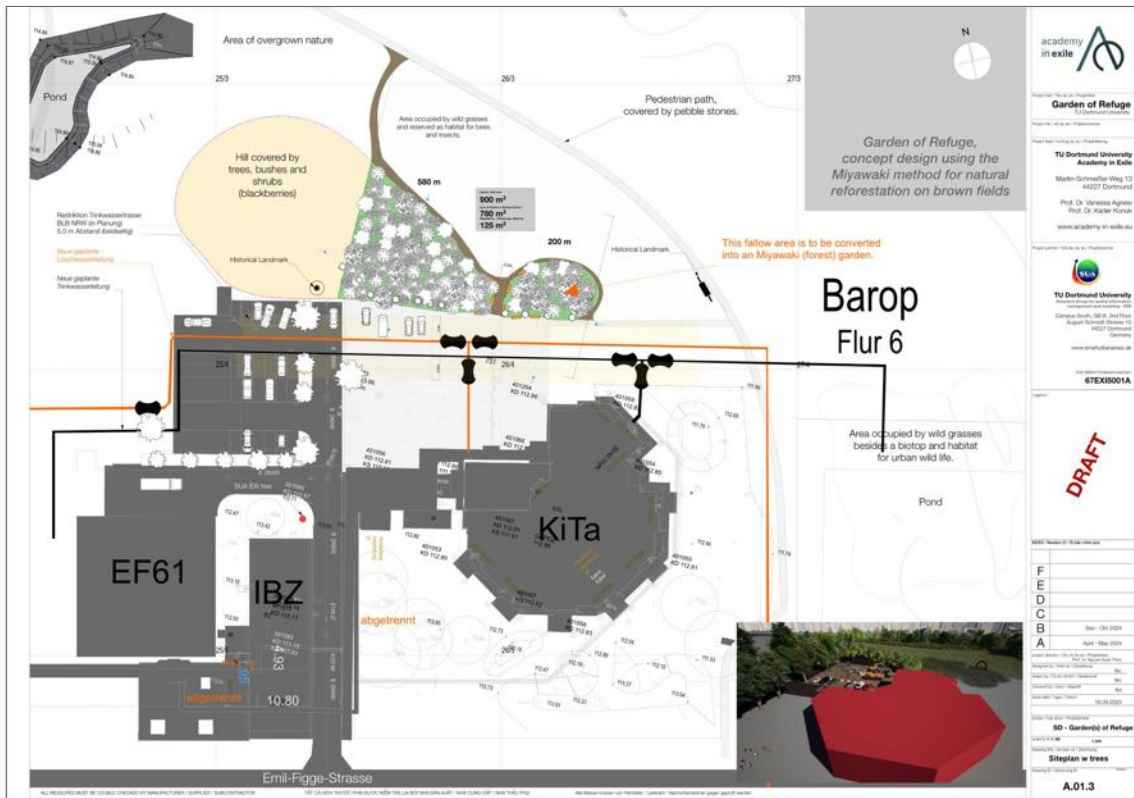
THÀNH QUẢ
 Văn bản số: 12.8.2020
 ngày: 9 tháng 5 năm
 ký tên: [Signature]

Appendix D.1: Impact Factor - TU Dortmund University Campus

During the course of the project, it was possible to build on a miniature prototype in Germany and to apply upscaled the so-called “tiny forest” system on the campus of TU Dortmund University. As a walkable research garden and forest in collaboration with the Academy-in-Exile⁴², the initial plans have been implemented and underwent changes due conditions on site. The ‘Garden(s) of Refuge’ is scheduled for completion by 2027. The illustrations provide information on the brownfield area to be renatured on the university’s North Campus, the subdivided vegetation plots with resilient and native plants, site sections, and visualisations prepared for communication with stakeholders and investors.



⁴² <https://www.academy-in-exile.eu/about/> (22.8.2024)



academy in exile

Garden of Refuge

TU Dortmund University
Academy in Exile
Martin-Schweller Weg 13
44227 Dortmund
Prof. Dr. Vanessa Agelton
Prof. Dr. Kadir Konuk
www.academy-in-exile.eu

TU Dortmund University
Campus Esch: Emil-Figge-Str. 10
44227 Dortmund
Germany
www.esch.tu-dortmund.de

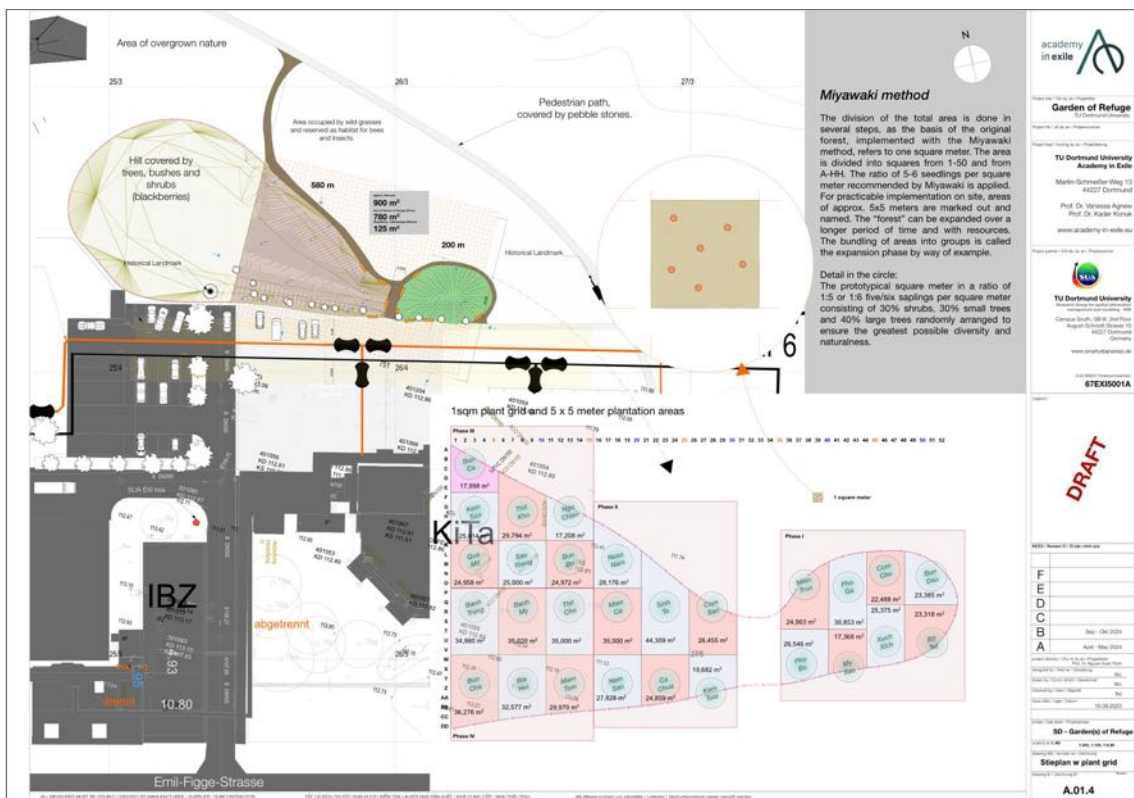
67EX0001A

DRAFT

SD - Garden(s) of Refuge

Siteplan w trees

A.01.3



academy in exile

Garden of Refuge

TU Dortmund University
Academy in Exile
Martin-Schweller Weg 13
44227 Dortmund
Prof. Dr. Vanessa Agelton
Prof. Dr. Kadir Konuk
www.academy-in-exile.eu

TU Dortmund University
Campus Esch: Emil-Figge-Str. 10
44227 Dortmund
Germany
www.esch.tu-dortmund.de

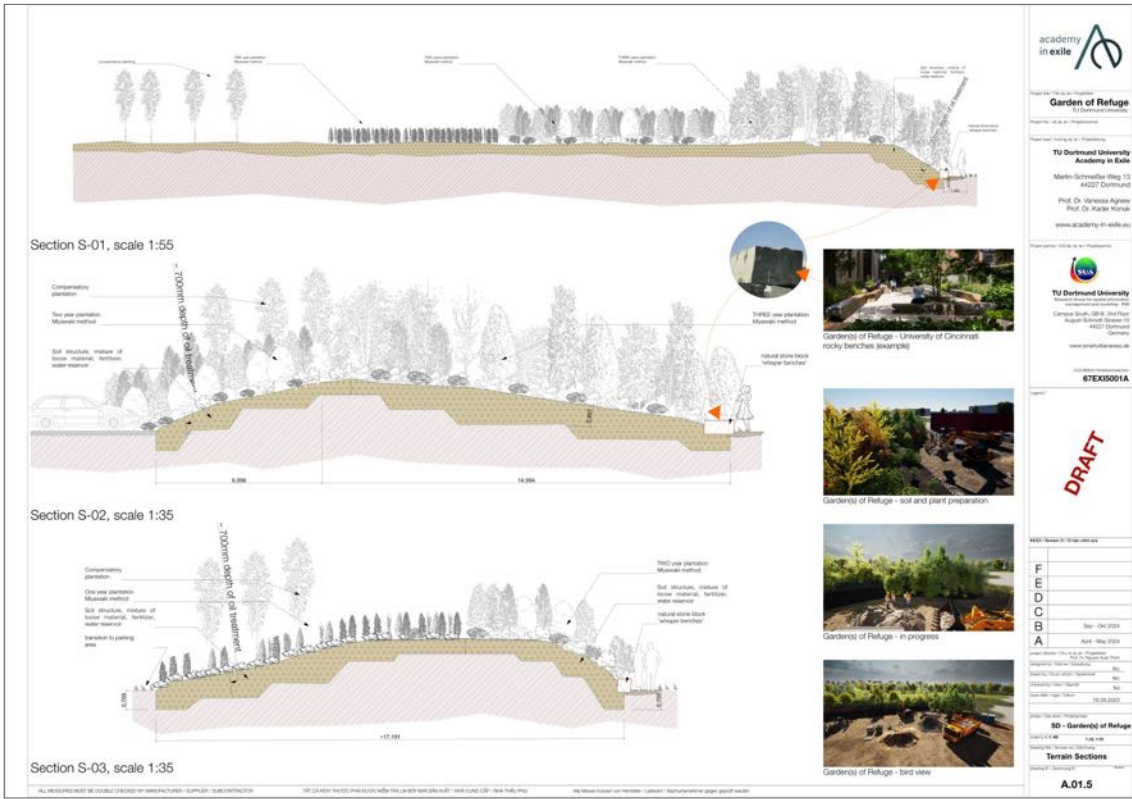
67EX0001A

DRAFT

SD - Garden(s) of Refuge

Siteplan w plant grid

A.01.4



academy in exile

Garden of Refuge

TU Dortmund University Academy in Exile

Martin-Schweifer Weg 13 44227 Dortmund Prof. Dr. Inesissa Aguilera Prof. Dr. Kai-Ina Konuk www.academy-in-exile.de

TU Dortmund University

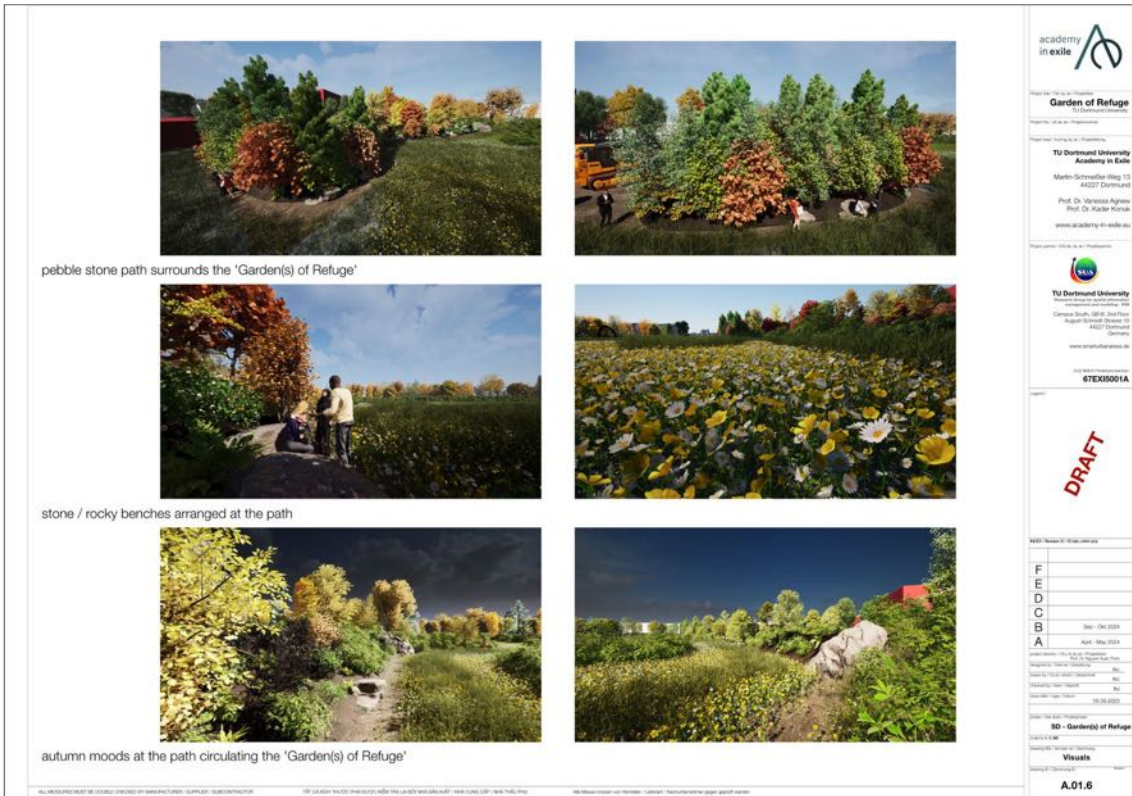
67EX0001A

DRAFT

SD - Garden(s) of Refuge

Visuals

A.01.6



academy in exile

Garden of Refuge

TU Dortmund University Academy in Exile

Martin-Schweifer Weg 13 44227 Dortmund Prof. Dr. Inesissa Aguilera Prof. Dr. Kai-Ina Konuk www.academy-in-exile.de

TU Dortmund University

67EX0001A

DRAFT

SD - Garden(s) of Refuge

Visuals

A.01.6

Declaration of Authorship

In accordance with §11 of the Doctoral Regulations of the Faculty of Spatial Planning at the Technical University of Dortmund, I hereby declare the following:

The submitted dissertation entitled

“Multidimensional Systems Approach to High-Rise Buildings and Urban Areas as Integral-Active Ecosystems. A case study in Hanoi, Vietnam.”

is the result of my own independent academic work.

I have used the academic resources and aids (books, journals, scientific articles, and data archives) explicitly referenced, and have not received unauthorised assistance from third parties. In particular, I have identified all content taken directly or indirectly from other works, whether quoted verbatim or paraphrased. Unless otherwise indicated, all figures, diagrams, and tables in this dissertation were created by the author. External sources and adapted graphical material are referenced in the respective captions.

For extended resources research and foremost translation from German into English language I have used the AI-tools DeepL, ChatGPT, Google Gemini and Perplexity in reciprocal-controlling combination.

This work, or parts thereof, has not been submitted previously to any university or academic institution, either in Germany or abroad, as part of an examination or qualification process.

All illustrations, technical engineered drawings and visual materials are original by the author unless otherwise stated and referenced when inspired by external sources. All content remains based on my own ideas, thoughts, research, and conclusions.

I solemnly affirm that I have declared the truth to the best of my knowledge and have not concealed anything.

Leipzig, Germany, February 2026