Research Plan

Architectural Methodologies for the Integration of Carbon-Sequestering Technology in High-Density Urban Context:

Structures into "Urban Trees" within the Contemporary "Urban Forest"

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MINING THE URBAN SKY

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Q1 Research Plan Submission 2023

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Choice of Studio

The studio collaborates with a wide range of stakeholders from the fields of science, government, civil society, and business and also welcomes interdisciplinary collaboration between engineering, science and architecture.

My personal interest in exploring the synergy between science and innovative technology for architectural integration perfectly aligns with the architectural engineering studio's mission, providing an ideal environment for developing groundbreaking methodologies that go beyond traditional architectural boundaries and meet the evolving demands of future architecture. Furthermore, my research requires a deep interdisciplinary collaboration with science and technology. This allows me to explore both practically-oriented and experimental design approach. The studio's expertise in circular economy flow, climate responsive design and research methods help me to formulate my own methodologies and support my fascination in exploring the architectural design intervention on emerging carbon capturing technology for the absorption of CO_2 in air, as a solution to the "world's most urgent mission" - global warming and carbon neutrality by 2050 (United Nations, 2020).

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RESEARCH TITLE - MINING THE URBAN SKY

Rejuvenating the abandoned power plant site into a carbon-sequestering Hub

“THE WORLD’S MOST CRITICAL MISSION” CARBON NEUTRALITY BY 2050 (UN, 2020)

01

RETHINKING BUILT-ENVIRONMENT AS A CARBON CAPTURING “FOREST”

Research Introduction

Informed by the principles of natural processes and ecosystems, this research contemplates the realization of urban landscapes characterized by **“building forests”** designed to actively sequester carbon. In addition to collaborative design process, the research is driven by the possibility that a building can remove carbon through a new approach to design within different high-density urban conditions.

Following the report from the IPCC and the UN, this research declares the need for rethinking how we design buildings, integrating a variety of regenerating systems and perfecting those technology already in development. This includes the use of carbon sequestering materials and high-tech solutions such as Direct Air Capture (DAC) by using a building’s stack effect to draw air in and out. The building that literally breathe in to remove carbon from the air. A building has the potential to sequester more carbon than what it emits whereas a single tree, the effects are limited especially in high-density urban context where the land space is limited due to rising population and the demand for more space. Thus, the research will explore how the integration of this specific technology of Direct Air Capture could be possible in architecture through design and altering the perception of buildings as “trees” in a metropolitan “forest”.

The research explores the solutions to integrate DAC carbon capturing technology through three different architectural design factors: facades, modules and building cores, simultaneously acknowledging the flow of chemical process, limitations and requirements of technology for the design integration.

Key Words

Carbon Capture, Industrial Site Revitalisation, Carbon Neutrality, Direct Air Capture (DAC), Global Warming, Building-Integrated Carbon Capture, Circular Carbon Economy

1. Global Warming and CO_2 Emission Continue to Rise

According to the International Energy Agency (IEA) and IPCC, the role of Carbon Capture, Utilization, and Storage (CCUS) is vital as a way of achieving net-zero emissions by 2050. Despite the increasing popularity of sustainable projects and policies, the IEA emphasized that achieving carbon-neutrality by 2050 would be impossible without the use of CO_2 capture technology. Why CO_2 emission continue to rise exponentially even with the effort of so-called sustainable architecture? This research finds that we urgently need to go negative emission, rather than being satisfied with “Less-Bad” projects.

2. Densifying Cities Increase Challenges for Green Areas with Natural Carbon Absorption Capacity

Although green areas are the must-have places for cities, the challenges of finding space became inevitable. As cities become increasingly more densely built, the available land area for such ecosystem services decrease. The urban population is estimated to increase by 2.5–3 billion. Additionally, today cities and urban areas are accountable for 71–76% of all greenhouse gas (GHG) emissions and 67–76% of all primary energy (PE) demand. A single tree is able to capture 25kg of CO_2 per year and we need to make our densifying city to capture CO_2 more efficiently. How can we tackle these growing urban issues?

3. Carbon Mitigation Strategies in Architectural Industry are Not Enough to Eliminate CO_2 Footprint

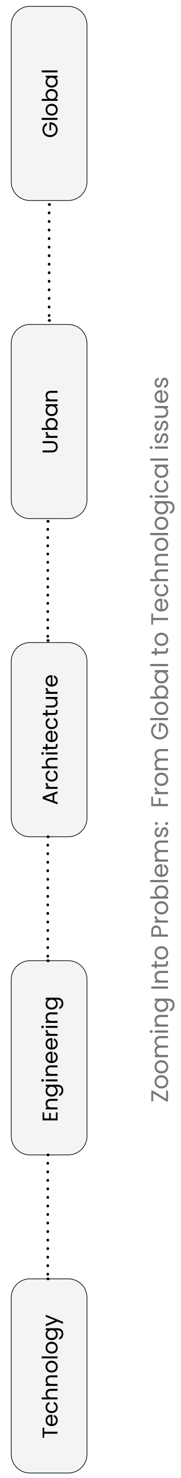
Architecture is responsible for about 40% of global CO_2 emissions, according to the International Energy Agency. This includes both the embodied carbon and he CO_2 emitted during the use and maintenance of buildings. It is vital to provide the building industry with a mechanism that can be incorporated within building designs to achieve carbon neutrality.

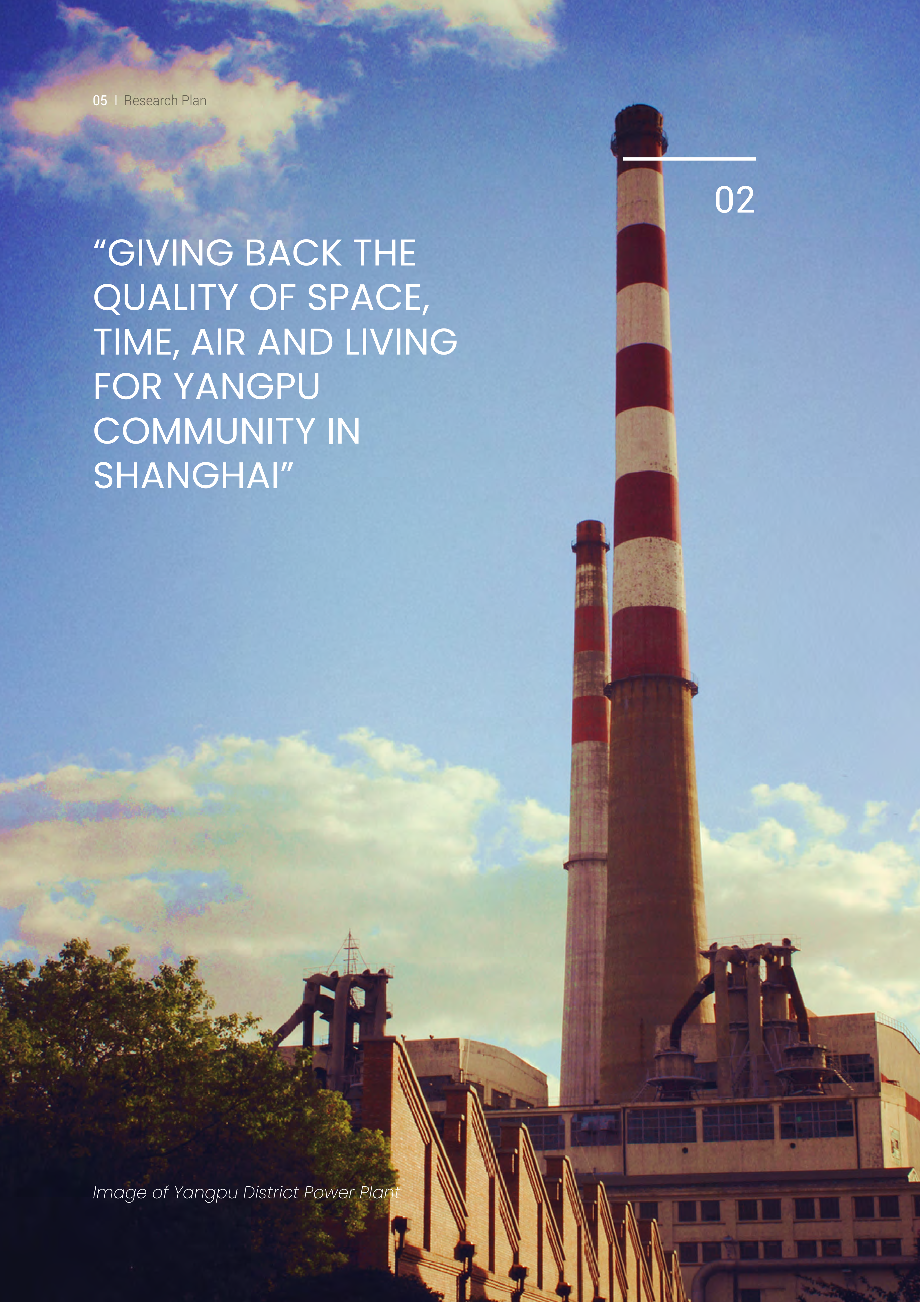
4. The Unappealing Industrial Technology of DAC limits the Access to Architectural Industry

From an architectural standpoint, Direct Air Capture (DAC) technology is often perceived as a utilitarian engineering component, characterized by substantial mechanical fans and steel structures, which may not align with urban aesthetic sensibilities. To facilitate the widespread adoption of DAC technology within built environments, the development of a comprehensive and visually appealing DAC framework for the architectural industry is required.

5. The high-density urban context limits the application of new technology

The scarcity of space within urban areas has become increasingly evident. Nevertheless, various factors impose constraints on the implementation of novel technologies within built environments. These include infrastructure limitations stemming from pre-existing utilities, the imperative of preserving historical structures, concerns regarding disruptions, and challenges related to accessibility. The most formidable hurdle often arises from issues of accessibility, where the introduction of emerging technologies, such as Direct Air Capture (DAC), necessitates not only specialized expertise but also access to specific equipment, materials, and machinery that may not be readily accessible or available within the confines of high-density urban settings.





02

"GIVING BACK THE QUALITY OF SPACE, TIME, AIR AND LIVING FOR YANGPU COMMUNITY IN SHANGHAI"

Image of Yangpu District Power Plant

Overall Design Objective

1. General Problems ········ 2. Research Objective ········ **3. Design Objectives**

1. Global Carbon Neutrality Through Adaptive Reuse

Although the major focus of the research is about the integration of carbon capture technology, the design initially focuses on taking the opportunities from the site of Yangpu District. Thus, in addition to carbon capturing, an appropriate carbon reduction strategy had to be placed by reusing the abandoned structures of the power plant, minimising the carbon emission during the construction and preserving the historical heritage of the local community.

2. Reversing the Role: From Historical Polluters to Future Carbon Eradicators - Giving Back to Yangpu Community

Within the overall objective of the research project, a high emphasis will be put on innovative ways of achieving the revival of heavily contaminated industrial site into a sustainable environment, which would function as a gigantic carbon-sink within the city. The research extends on advancing circularity and sustainable principles within architecture during the process by adapting the priciple of circular carbon economy. Thus, the objective of design is to return what was taken away back to the site due to severe industrial activities in the past and the site is given a new opportunity to "apologise" by reversing the role as a carbon eradicator.

3. Technologically Innovative Yet Socially and Economically Responsible Local Mixed-Use Environment

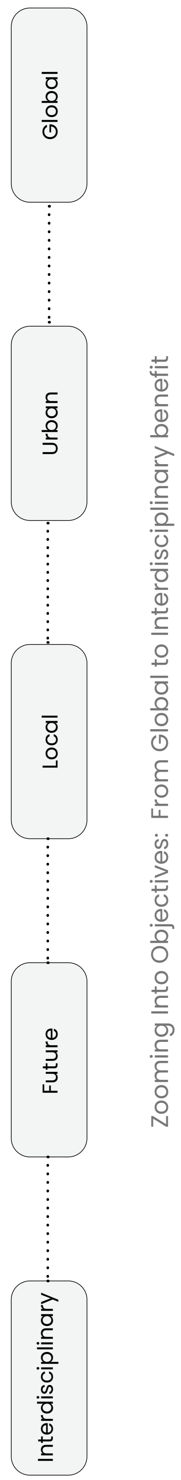
The cutting-edge carbon capturing engineering such as Direct Air Capture is just a small part of the entire architectural approach. Therefore, the well-being of both the environment and the Yangpu community should be holistically addressed: It seeks to create sustainable, circular, and affordable urban living solutions that not only reduce carbon emissions but also enhance residents' quality of life, contributing positively to the urban community and the planet

4. Setting a First Example Beyond Traditional Boundary

Following China's declaration on gradually closing all the coal-power plants, the design aims to create a first examplar direction to respond to the future trend to regenerate them. Realistically, this research project acknowledges that it may not singlehandedly revolutionize the fight against global warming or absorb all of Shanghai's carbon emissions. However, it endeavors to develop a comprehensive methodology for the revitalization of abandoned industrial sites, effectively transforming them into carbon sinks. This initiative aims to set an example of urban carbon reduction and absorption through architectural methods, signaling the evolution of architectural practices beyond traditional boundaries.

5. Aesthetically Pleasing Integration of Carbon Capture Solution That Promotes Interdisciplinary Collaboration

As an integral component of the design methodology, extensive collaboration and consultations will be undertaken with a Doctoral Candidate specializing in Carbon Capture in Chemical Engineering Department at TU Delft. This collaborative effort aims to formulate a pragmatic solution for the seamless yet aesthetically pleasing integration of direct air capture technology. It will focus on energy consumption, the assessment of CO_2 capture capabilities, and the rigorous testing of its impact on CO_2 reduction for the application of design integrated technology in the high-density urban context of Yangpu. Thus, the design objective is to promote diverse collaboration between science, technology and architecture.



Overall Design Question

03

***How** can we leverage cutting-edge carbon sequestration technology and the architectural workflow of prefabrication and modular design to extend the principles of the circular economy and create a comprehensive design methodology through the transformation of an inactive power plant site situated in the high-density Yangpu district, into a carbon sinking Mixed-Use Research Centre?*

A vision for mining the urban sky and resilient high-density urban regeneration of the highly polluted city of Shanghai

Reflection on Relevance

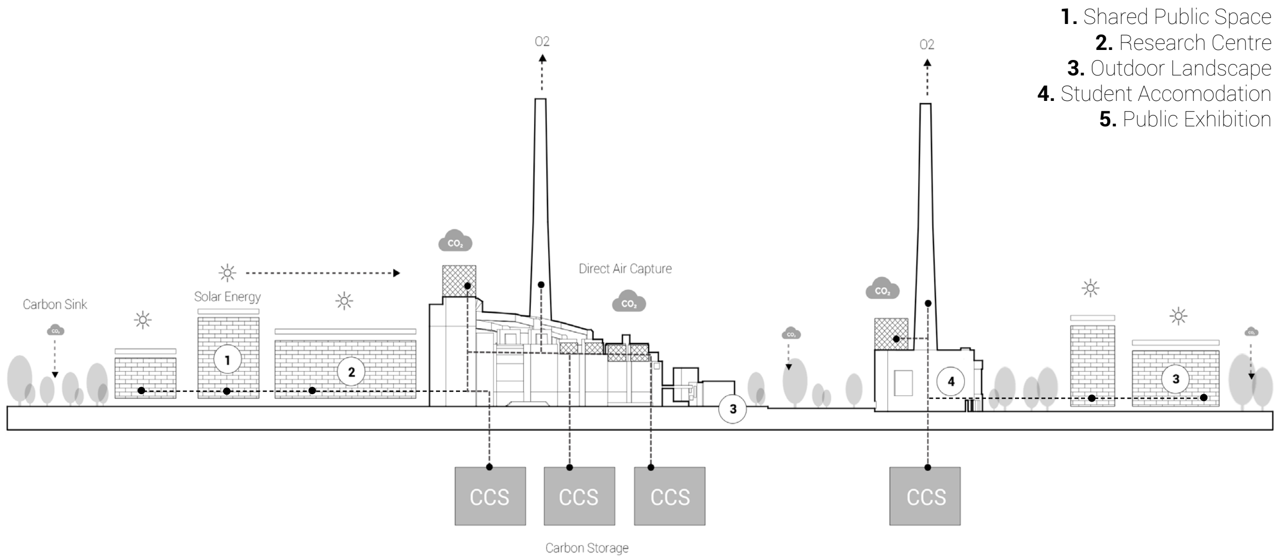
To repurpose the inactive power plant site in Yangpu into a carbon-sinking Mixed-Use Research Centre, the design will merge advanced carbon sequestration technologies (Direct Air Capture) with the principles of prefabrication and modular design as construction tools for architectural application.

The design essentially aims to create a self-sustaining, adaptable, and environmentally responsible structure that not only captures and stores carbon emissions but also serves as a hub for research and innovation in sustainable technologies. This project will exemplify a circular economy approach by integrating sustainable material sourcing, modular construction, and an adaptive design that evolves with changing research needs and environmental conditions.

Thus, the application of Direct Air Capture Technology through architecture is only a part of the design scheme to extend the circular economy principle beyond the carbon "reduction". The holistic approach towards combining both reducing carbon footprint and capturing emitted carbon and eventually storing would be the technical direction of the design project along with the aims of creating a resilient and livable mixed-use Yangpu community that responds to the demands of the site.

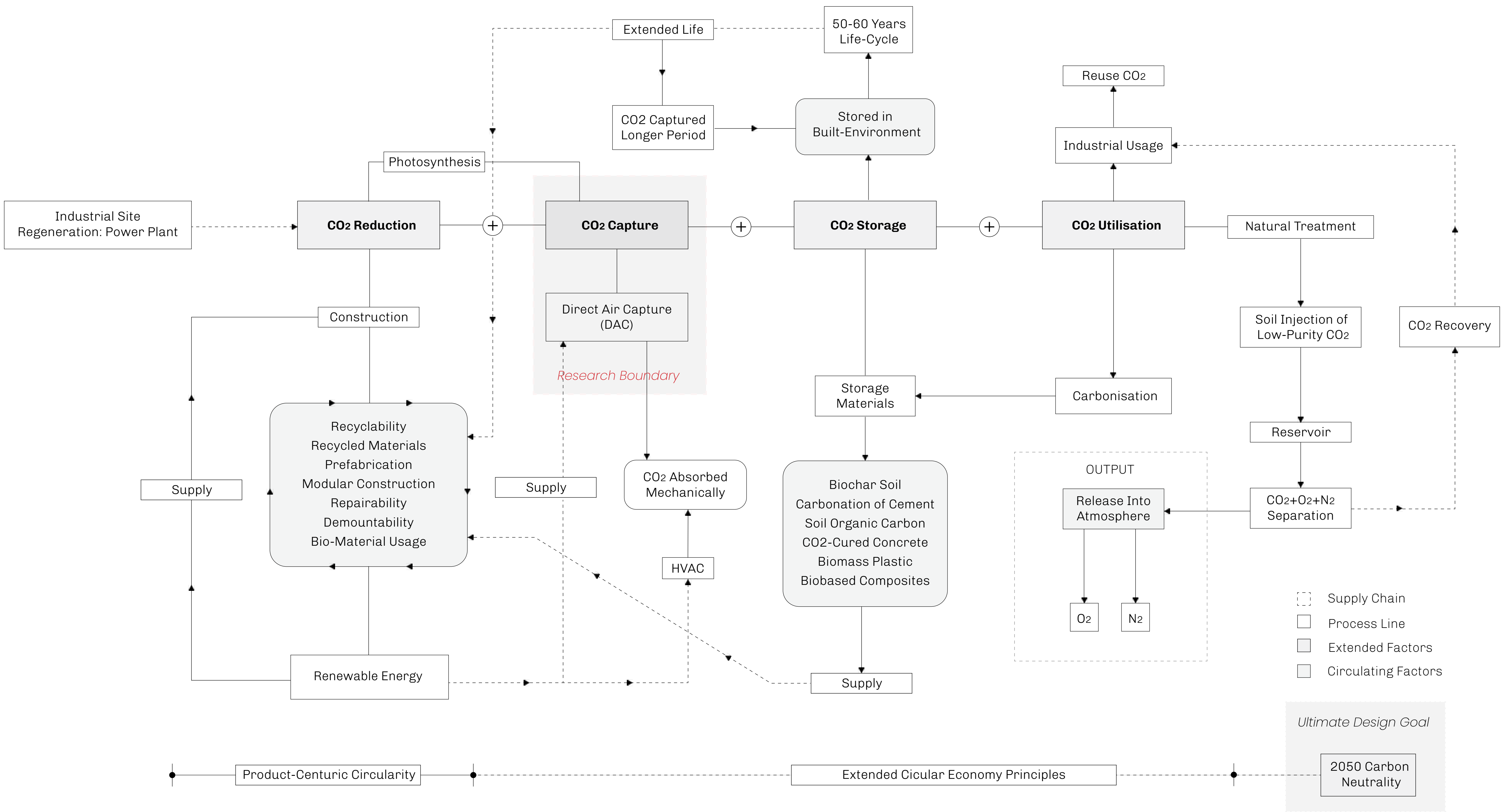
As a result, the societal point of view can be highlighted by a general aim of "**giving back" the lost qualities of the site** to the existing community and nature, and eventually, contributing to carbon neutrality through a metropolitan carbon-sink.

Furthermore, In terms of the user-point of view, it becomes more specific by targeting both surrounding and nearby neighbourhood. The design aims to link as a public central sustainability research hub that connects 9 technical universities within 10km distance from the site and 36 universities in the city of Shanghai, contributing to Shanghai's mission of Sustainable innovation and growing environmental awareness in China.



Planning for a Transformation of Abandoned Power Plant Site (Own-image)

General Design Objective: Implementing Carbon Reduction, capture, storage and utilisation Strategy



04

"THE IPCC HAS RECOGNISED THAT CARBON REMOVALS ARE CRITICAL TO ADDRESSING CLIMATE CHANGE,

IT'S TIME TO ACT" (MCKINSEY, 2022)

Research Focus

Catalyzing Urban CO2 Neutrality: Prefabricated Modular Architectural Frameworks for the seamless Integration of Direct Air Capture (DAC) Technology in High-Density Urban Environments

1. General Problems → 2. Research Objective → 3. Design Objectives

Global ▸ Global

1. High-Density Cities As Metropolitan Forests

According to the latest report from the United Nations, our future is undoubtedly urban. Urbanisation and densification of cities will remain one of the most powerful mega-trends of the twenty-first century. Currently 50% of the population lives in cities and it will continue to grow and reach 70% by 2050. The problem rises due to the carbon emission as a result of densification and reduction in green areas with carbon-sequestering capacity. Thus, the research objective is to turn the cities into metropolitan forests by transforming our buildings to operate as the "trees".

Urban ▸ Urban

2. Prefabricated Modules With Integrated DAC

The prefabricated living modules could be the standard container size or customised into new volumes The living modules are connected to a corridor, core and facade, in order to form a complete building. Thus, the prefabricated facade becomes the "leaf", the module becomes the "stem" and the building core becomes the "tree trunk" which in combination, mimics the mechanism of a carbon-capturing tree. The use of prefabricated modules allow easier integration of the new carbon capturing technology as it could be produced and adapted within a controlled factory environment. Furthermore, it could reduce the issue of site disturbance and carbon emission during the construction.

Architecture ▸ Local

3. Building That Absorbs More CO_2 Than It Emits

If our buildings could absorb more carbon than they emit, we can theoretically move towards the negative carbon emission. This is the critical aspect of the research as it concludes that the current state of so-called sustainable buildings are still not enough to tackle the global warming issue. This is because these buildings are only able to reduce the emission but still contributes to positive carbon emission. The objective of the research is to go beyond "reduction".

Engineering ▸ Future

4. Seamless Integration of CO_2 Capture System

The objective of the research is to integrate this carbon capturing technology in an aesthetcially pleasing and efficient way. As a result, providing a set of parameters and design guidelines, which could be implemented and tested through the application to real-life context.

Technology ▸ Interdisciplinary

5. Economically and Environmentally Feasible

ALthough the integration of carbon capture technology with Direct Air Capture (DAC) method is based on the hypothesis that the buildings perform as "trees", it is crucial to address the feasibility of the hypothesis. This is because the integration could be resulting in emitting more carbon or economically not practical. Thus, the research aims to discover the optimal design guidelines (such as minimum and maximum ceiling heights) which offers the most affordable and environmentally feasible application into real-life context. This could be done by identifying the cost of installation and operation, carbon captured per year, energy demand and number of years to offset the carbon emitted during operation and construction of a building.

05

Thematic Research Question

How can architecture strategically integrate emerging CO_2 capturing technology through an architectural design methodology?

Image of Current Direct Air Capture(DAC) Technology

Sub Questions of Research Question

- How can standardised prefabricated modular construction be implemented to enhance urban carbin mitigation and sustainability while responding to urban issues.
- Can the Electrochemical Process of Direct Air Capture be Harmoniously Integrated into Building Design, Embracing Both Functionality and Aesthetics?
- Can the Direct Air Caputre (DAC) process be fully operated by on site renewable energy? How much energy would be required and what are the available sources?
- How can the combined integration of DAC in architecture and modular construction increase sustainability and solve local and global issues especially in the context of high-density urban settings?
- How can we look beyond our building industry into emerging scientific development and leverage some of the negative emission technologies that exist?
- How effective would DAC integrated architecture be towards carbon neutral goals?
- How can DAC method be designed to create a suitable and applicable solution for new buildings?
- How can DAC be architecturally integrated using natural ventilation (cross and stack-effect) to contribute to seamless and energy efficient building system.

Reflection on Relevance

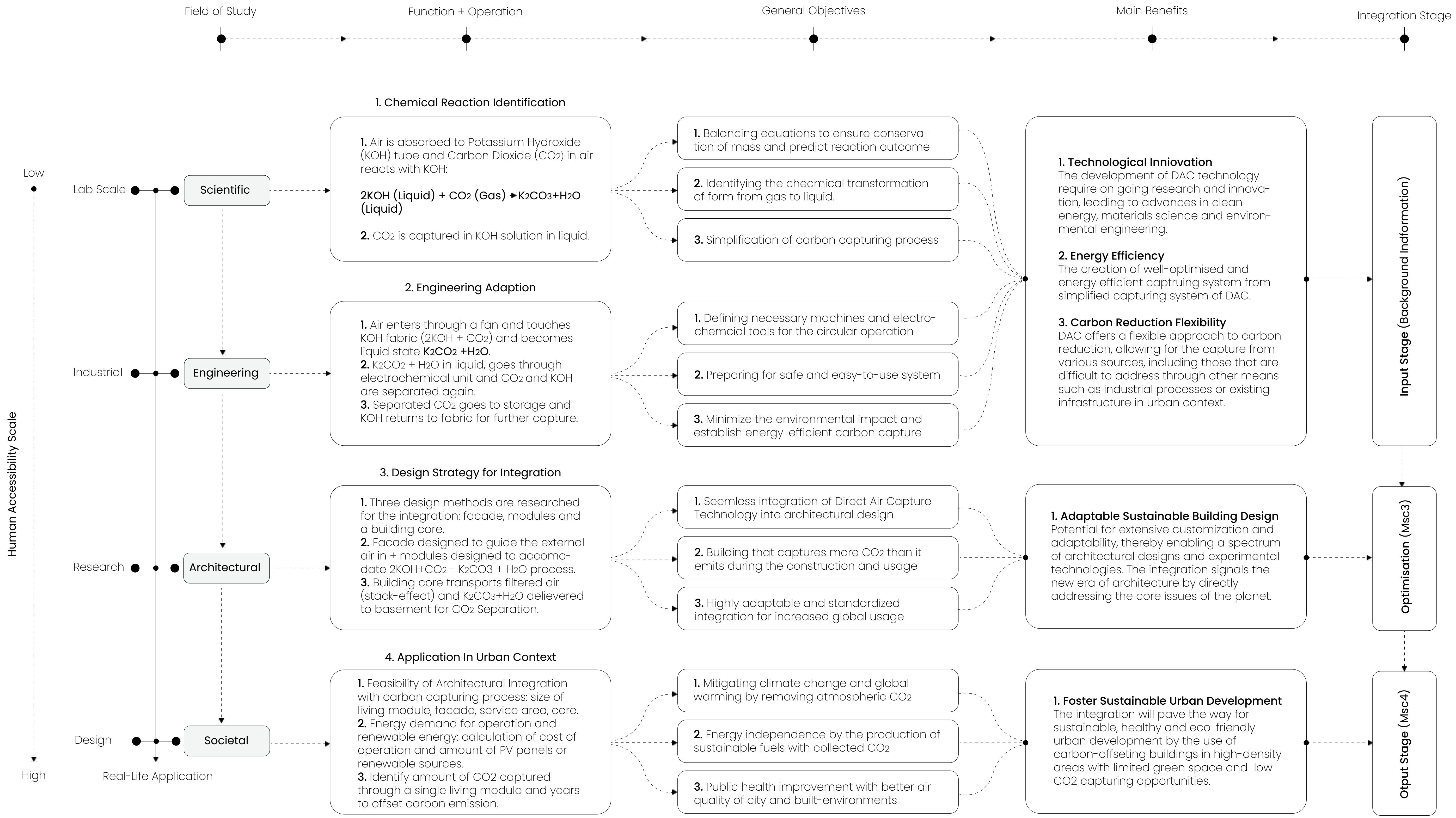
The integration of Direct Air Capture carbon capturing technology (DAC) in architectural design framework specifically targets sites in high-density urban areas. This is due to both societal and scientific objectives and benefits.

Scientific

Direct Air Capture (DAC) technology, a recent development by chemical engineers, offers a promising solution for mitigating global warming by capturing CO_2 from the atmosphere. However, its use in urban areas has been limited due to space constraints and aesthetic concerns. The research objective is to integrate CO_2 capture within urban buildings, utilizing design elements like modules, facades, and building cores. This approach not only enhances efficiency but also reduces costs. Urban areas benefit from naturally higher CO_2 concentrations (above 400ppm), requiring less energy for capture, and natural ventilation can replace conventional fans to draw the air into the integrated system.

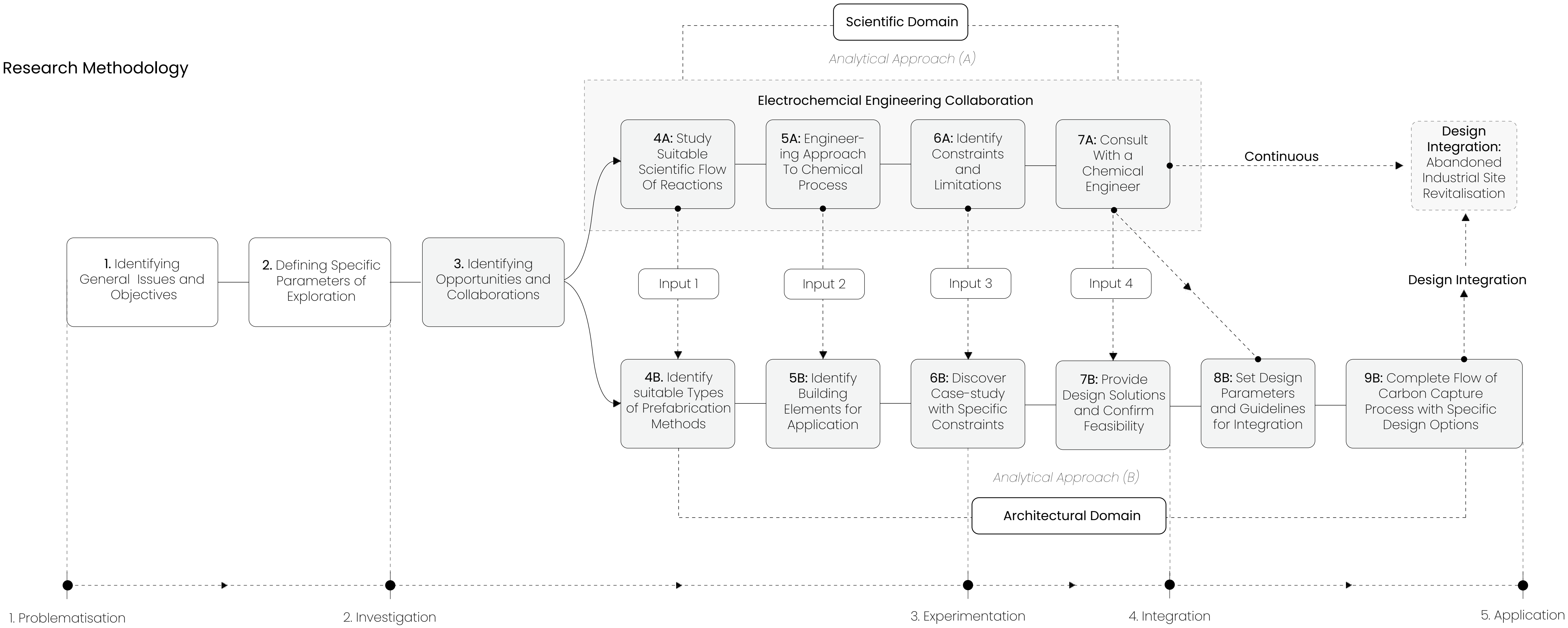
Societal

The research aims to drive architectural innovation while directly addressing global warming. It also seeks to enhance public health by reducing CO_2 concentrations both inside and outside buildings, with a specific focus on urban areas like Shanghai (450-500ppm), where air pollution is a pressing concern. In summary, the societal objective is to foster sustainability, improve urban air quality, and promote environmental responsibility, ultimately creating healthier and more resilient cities for their residents.



01. Research Methodology : Architecture Translating Scientific Advancements to Tangible Societal Advantages

Research Methodology



1. Main Qualitative and Quantitative Methods of Research

Stage	Qualitative Methods (Interpretation)	Quantitative Methods (Numerical)
1. Problematisation	Correlational research and global organisational policies on urban and climate issues	IPCC and IEA reports on amount of CO_2 released to atmosphere and urban densification data
2. Investigation	Literature review and case studies to identify the opportunities and specific demands	Investigate carbon capturing capacity and energy required at different scales of DAC system
3. Experimentation	Experimental research to study the impact of potential design solutions	Simulation and modelling of the design options with DAC system integrated - Prototyping
4. Integration	Complete design options of integrated DAC system and provide parameters for future use	Collaborative research to Calculate efficiency and impact of integration to confirm feasibility
5. Application	Site investigation and define programs of demand for real-scale project application	Find site area, soil status, CO_2 concentration in atmosphere and energy efficiency + cost.

MSc 3 (stages 1–4); MSc 4 (stage 5)

Theoratical ------- Hypothesis ------- Technical ------- Realisation

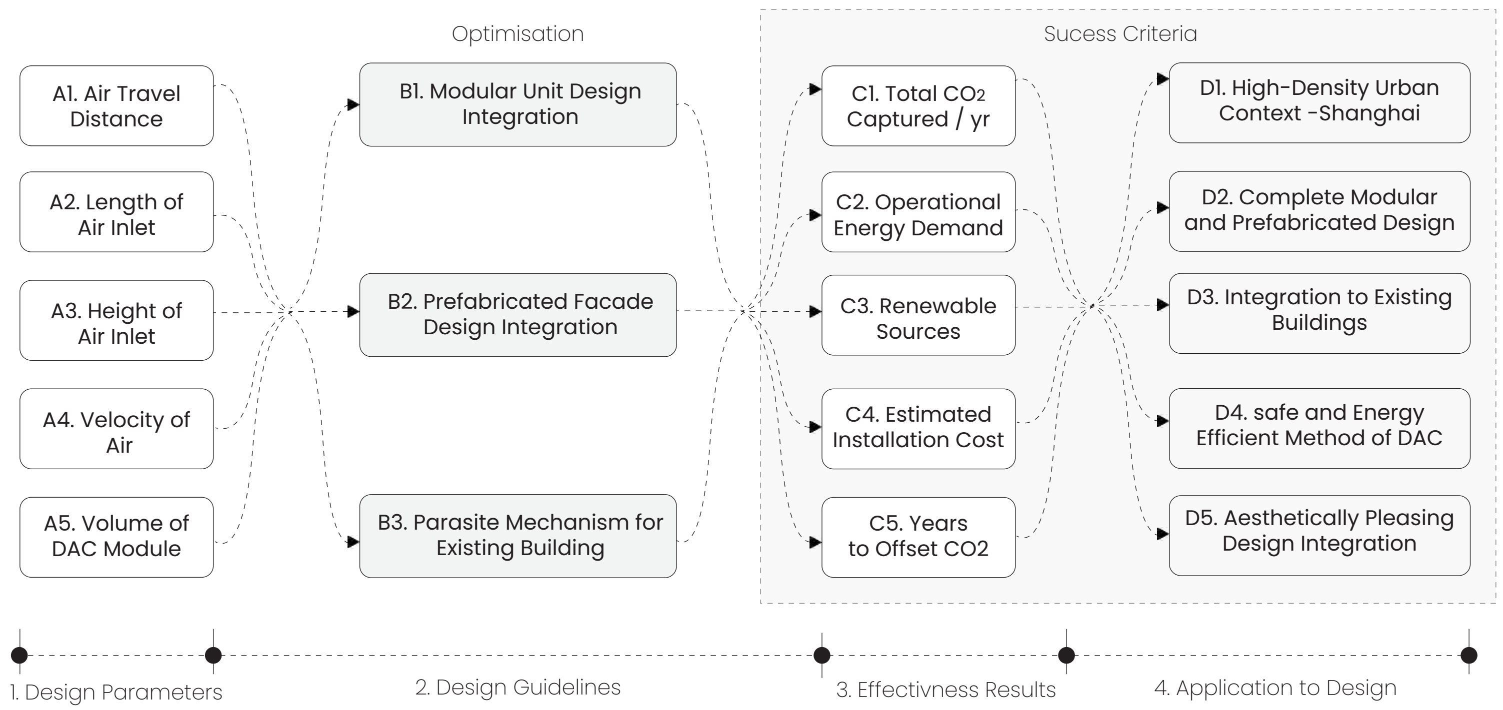
02. Research Methodology: Dual Analytical Approach

The methodology for this research begins with a comprehensive problematization of the issue at hand. Subsequently, a **dual analytical approach** is undertaken (from 4A and 4B) , involving the simultaneous examination and observation of two distinct fields of study. These fields, namely the scientific and architectural domains, are meticulously investigated in parallel, with the ultimate objective of amalgamating their insights to formulate an innovative approach to the application of carbon sequestration with DAC technology within the built environment.

Within the scientific domain, the focus initially rests on the intricate mechanisms how the scientific flow of chemical reactions to capture carbon results in creating potential integration methods to both architecture and engineering. The study of scientific reactions (4A) of carbon capture process results in identifying the engineer's approach to accomodating the flow of reactions (4B), which simultaneously influences on identifying suitable building elements for potential application such as facade, modules and cores (as mentioned in the previous page). Throughout the research process, a deep collaboration with a chemical engineer at TU Delft is carried out, for identification of constraints, limitations and idea exchange for the feasible building integration.

Within the architectural domain, input 3, begins from identifying constraints and limitations in engineering field. In order to deal with these constraints, various case-studies will be carried out to discover how other researchers, architects and professionals approached a specific issue: for example the process of air capturing by Smog-Free Tower, prefabrication and modular construction by citzen M hotel, Student housing in the Houthavens in West with remarkable adaptability and planning for successful integration of various functions. The outcome of case-studies will influence the experimentation stage to provide various design solutions such as facade integration for air inlet and ceiling module for carbon capturing and a building core for, CO_2 and air transportation. Feasibility of these design solutions will be consulted with the engineer (energy efficiency, volume, noise, locations of systems, etc).

Journey of Parameters For Design Implementation of CO_2 Capturing in Architecture



Outcome of Prefabrication and Modularity For Carbon Capturing Integration

Architectural Domain

In the context of densely populated urban environments, the need for **expeditious and efficient construction methods, while concurrently minimizing disturbances to the urban landscape**, assumes paramount significance. Additionally, the profound potential for extensive customization and adaptability, thereby enabling a spectrum of architectural designs and experimental technologies, underscores the strategic importance of these attributes.

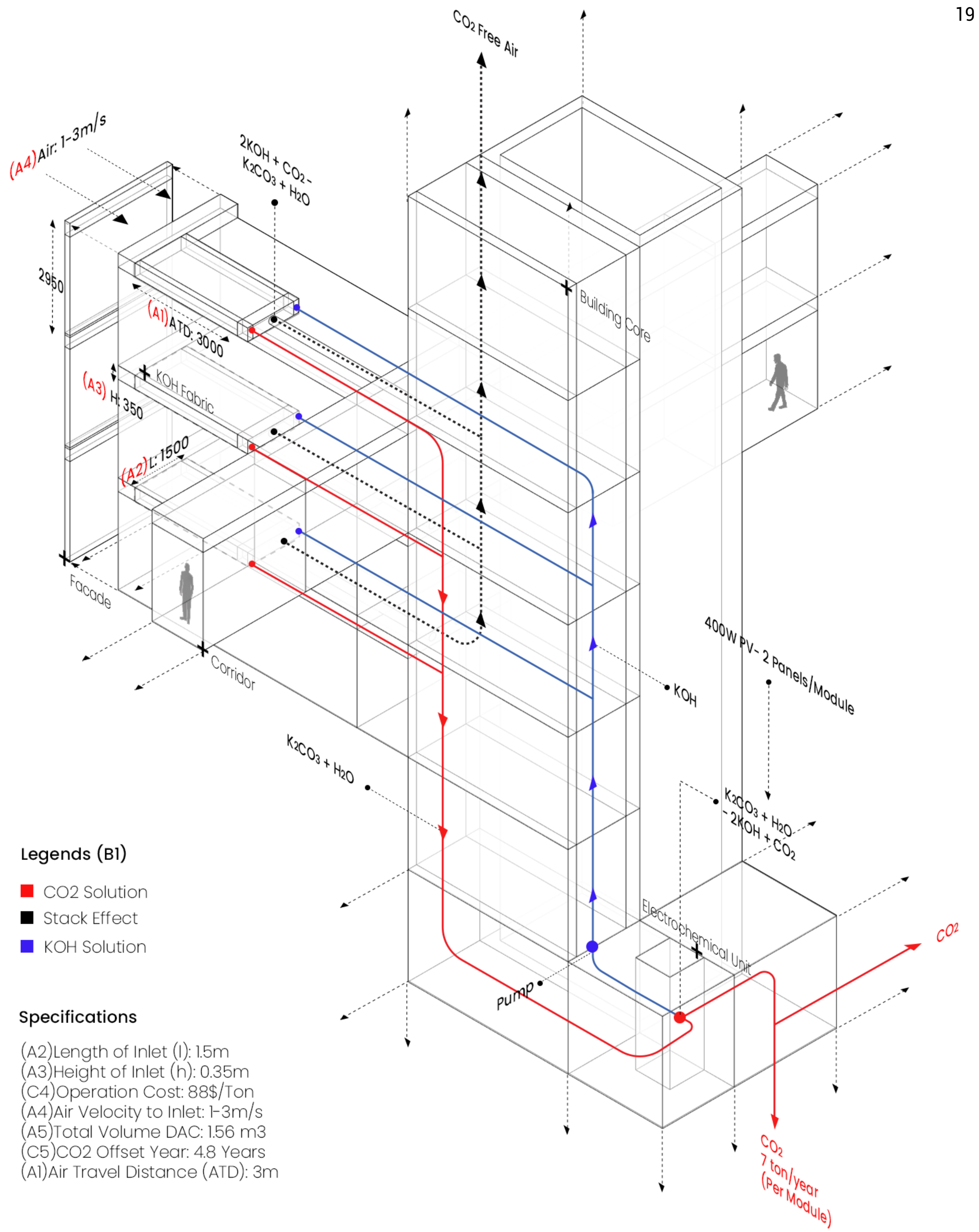
The remarkable degree of flexibility and adaptability forms the linchpin for the unobtrusive integration of carbon capture technology. Significantly, this approach **adeptly navigates the multifaceted challenges intrinsic to conventional construction techniques, particularly when introducing technological amalgamation.** Consequently, the choice of modular construction as the foundational framework for the seamless incorporation of Direct Air Capture (DAC) technology within high-density urban settings emerges as a judicious decision grounded in these compelling considerations. **DAC can blend with the overall aesthetics of the space. By strategically placing air inlets, outlets, grilles, pipes and units, the integrated systems can be seamlessly integrated into the architectural design,** enhancing the overall appeal of the building.

Expected Results of Thematic Research Design Implementation

Using the Knowledge Within Design Approach

The current stage of integrating Direct Air Capture (DAC) technology within architectural frameworks is situated within the developmental phase, as practical implementation has never realized. Researchers from Aalto University's Department of Environmental Engineering have classified this integration at a Technology Readiness Level (TRL) of 6, with a "Medium" rating in terms of current feasibility for construction and its climate impact within the built environment. The research builds a hypothesis that this **level of impact and readiness could be boosted through an appropriate architectural method of design integration.** Furthermore, the research aims to **set the first example of how several design options and parameters could lead to the carbon-capturing capacity, cost, energy requirement (solar panels), and CO_2 offset years.**

Consequently, this research acknowledges that a well-conceived architectural design integration of advanced carbon capture systems could effectively yield negative emissions, **thereby making a substantial contribution to the realization of a "building forest."** Furthermore, the study identifies prefabricated modular architecture as one of the most realistic and ideal mechanism for facilitating the integration of carbon capture technologies into urban contexts, given its enhanced adaptability and capacity for customization, thus making it particularly suitable for urban environments such as Shanghai (my desgin context). Ultimately, this research underscores the substantial promise of an interdisciplinary approach and signals the evolution of architecture beyond conventional boundaries, **with a pronounced focus on carbon neutrality, specifically emphasizing the capability to capture more carbon than it generates.**



Stage 8B (Hypothesis Based): Design Parameters and Guidelines Example

Design parameters are set to 5 different factors: Air Travel Distance (ATD), Length of Air Inlet (l), Height of Air Inlet (h), Air Velocity to Inlet and Total Volume of DAC system. These 5 parameters generate multiple design guidelines such as "Modular Unit Integration" as shown above, and "Prefabricated Facade Louvers Integration". As a result, the effectiveness of each design guideline is tested and optimised based on the energy requirement, CO_2 offset period, amount of CO_2 Capture per year, number of PV panels, and estimated total cost. The research will further showcase how these parameters affect the outcome of these 'effectiveness' results for the future application of design integrated system.

Desired outcomes and requirements will be set after the introduction of design guidelines as shown above. For example, minimum ceiling height, inlet size, legth and width of a modular unit would be introduced for optimal performance and efficiency of carbon capturing building. This would also inform my final design project in msc4.

06

Glossary of Key Terms

01. Direct Air Capture

According to the International Energy Agency (IEA), direct air capture (DAC) technologies extract carbon dioxide directly from the atmosphere at any location, unlike conventional carbon capture which is generally carried out at the point of emissions, such as a steel plant. The carbon dioxide can be permanently stored in deep geological formations or used for a variety of applications. The process of Direct Air Caputre in engineering operates with a mechanical fan to extract the air in and the collected air touches the embedded carbon capturing solution (such as Potassium Hydroxide) (IEA,2023).

02. Carbon-Sequestration

Carbon sequestration (or carbon storage) is the process of storing carbon in a carbon pool. Carbon sequestration is the capturing, removal and storage of carbon dioxide (CO2) from the earth's atmosphere. It's recognised as a key method for removing carbon from the earth's atmosphere.There are two main types of the sequesteration: biological and geological. Biological sequestertion refers to forests, woodlands or oceans, which are naturally capable of capturing and storing carbon and create carbon-sinks. Geological carbon sequestration happens when carbon is stored in places such as underground geological formations or rocks (Nationalgrid,2023). This process is largely artificial or 'direct'. The technology of Direct Air Capture also belongs to this geological sequesteration.

03. Circular Carbon Economy

Circular Carbon Economy (CCE) offers a new way of approaching climate goals that implicitly values all options and encourages all efforts to mitigate carbon accumulation in the atmosphere. The circular carbon economy extends the concept of a circular economy (reduce, reuse, recycle) by including remove and focusing exclusively on carbon and energy flows. (UNFCC)

04. Carbon-Neutrality

Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration. In order to achieve net zero emissions, all worldwide greenhouse gas (GHG) emissions will have to be counterbalanced by carbon sequestration (Europeanparliment, 2023).

05. Building-Integrated Carbon Capture

Building-integrated carbon capture is the new envisioned mechanism that is embedded into buildings. As a result, the buildings become capable of absorbing carbon dioxide from the atmposhere and provide a solution to store and covert into carbon-based materials or inject into soil without negatively impacting the environment. The mechanism relies on the engineering process of Direct Air Capture in collaboration with design methodologies for the integration.

07

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08

Planning: Research and Design Timeline

The timeline below shows the planning of the research until P2. Although the table shows the detail planning, it is anticipated to change according to the duration of each research stage. The three fields: research, design and context and engineering consultation are carried out simultaneously as this would allow informed-decision based design for P2. Research development continues with investigtion all the way towards the P1 assessment. Page 15 research methodology is the core of this research and design timeline.

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<tr><td>DATES</td><td>5,7 Sep</td><td>12, 14 Sep</td><td>19, 21 Sep</td><td>26, 28 Sep</td><td>3, 5 Oct</td><td>10, 12 Oct</td><td>17, 19 Oct</td><td>24, 26 Oct</td><td>31 Oct, 2 Nov</td><td>7, 9 Nov</td><td>14, 16 Nov</td><td>21, 23 Nov</td><td>28, 30 Nov</td><td>5, 7 Dec</td><td>12, 14 Dec</td><td>19, 21 Dec</td><td>26, 28 Dec</td><td>2, 4 Jan</td><td>9, 11 Jan</td><td>16, 18 Jan</td><td>23, 25 Jan</td><td>30 Jan, 1 Feb</td></tr>
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Mind the Planet?

MINE THE URBAN SKY