EcoCircuit, a Text2Flow Application: Deciphering Environmental Metabolism Through Staging and Collaborating with Language Models

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Abstract: Landscape architecture, a discipline that crafts a creative and integrated vision of a site while navigating underlying complexities of the environment, is rapidly evolving with the surge of AI tools and large language models (LLMs). This leads to a pertinent question: Can AI grasp the nuanced intricacies in portions of landscape architecture or entire design concepts to enhance environmental comprehension and invigorate the creative process? In this instance, we focus on the metabolic understandings of site, systems, and large sale city planning around 'urban metabolism', and if AI can assist in innovating at the systems performance cycles level of a project, and in the graphics which illustrate those processes. Building upon designers' existing practices in platforms like Midjourney and ChatGPT to generate ideas in text and images through prompts, this research developed a new tool to decode environment metabolism: EcoCircuit. EcoCircuit, empowered by LLMs, features a Text2Flow workflow that allows users to input an environmental description and generate complex landscape flow visuals. These visuals, intricately representing landscape metabolisms, leverage visual problem-solving with the Chain-of-Thoughts LLM reasoning framework of staging prompts.

Keywords: Artificial intelligence, language models (LMs), metabolism, generative flow diagrams

1 Introduction

Landscape architecture is a discipline that crafts a creative and integrated vision of an environment while navigating the underlying complexity of invisible dynamics. These dynamics are often referred to as "metabolism", a term that captures the essence of the landscape's living, breathing nature and is often visualized through flow diagrams by landscape architects (FIELD OPERATIONS 2014) (Fig. 1). The metabolism encompasses a network of interconnected technical systems, bringing together landscape architects, civil engineers, planners, decision-makers, and stakeholders. This collaboration fosters growth, sustainability, and a circular economy.

Traditional methods may conduct detailed site surveys to synthesize complex metabolic understandings of the environment into the flow visuals. First, humans list the helpful existing resources as inputs and envision valuable outputs to generate. Then, people would research and ideate potential technologies, materials, or operations between the input-output as sequenced processes, various resources, and systems that interplay as co-optimization and capture a portion of the outputs for feedback to regenerate resources. Creating this metabolism requires deep collaboration across different disciplines and extensive knowledge to reach the complexity of these dynamics, but many of these dynamics are known physics and chemical foundations in our modern world.

The rise of Large Language Models (LLMs) such as OpenAI's GPT series, trained on vast amount of textual data, designed to understand, generate, and interpret human language, enables the catalytic capabilities on a wide range of language-based tasks. Beyond textual un-

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derstanding, LLMs can also relate to images through techniques like image captioning, visual question answering, and generating text-based descriptions of images. Staged reasoning frameworks such as Chain-of-Thoughts (CoT) (WEI et al. 2022) and Tree-of-Thoughts (ToT) (YAO et al. 2023), coupled with LLMs, significantly advanced deliberate AI's problem-solving capabilities. These frameworks enhance reasoning by staging prompts along single or multiple reasoning paths. They deliberately break down the complex tasks into simpler stages and incorporate targeted few-shot learning examples at each stage. This approach enables each stage to become a more manageable return for LLMs, with the return of one stage as part of the prompt for the next. They have proved effective in tasks requiring non-trivial planning or research, including games, creative writing, and mini crosswords. Inspired, *EcoCircuit* introduces a framework to visually break down information-intensive graphics like environment metabolism. Our contributions are summarized as follows:

1) We developed staged LLM prompts based on the CoT method to decipher the complexities of landscape metabolism. This includes understanding inputs and outputs, processes and co-optimization, regeneration/feedback, and system dynamics.
2) We introduced a Text2Flow interface, where flow visuals of landscape metabolism are generated by simply entering a description of an environment. The interface processes this information, utilizing LLM-generated metabolism knowledge through CoT to create structured databases visually represented as nodes and flows.
3) *EcoCircuit* introduces an iterative interface for interactions: Create, Read, Update, and Delete (CRUD). This feature highlights LLMs' potential to enhance design iteration and potential AI-human collaboration.

Fig. 1: Landscape designs and metabolism diagrams by Field Operations (top two) and BIG Bjarke Ingels Group (bottom two). Field Operations's "Urban Metabolism" unfolds the flows of a subterranean heat network utilizing industrial waste heat, and ecological integration of unused port areas in Rotterdam (FIELD OPERATIONS 2014). Metabolism city system drawing for Oceanix Busan highlights key inputs and outputs for various city systems, including energy, waste, water and food (BIG BJARKE INGELS GROUP 2022).

2 Related Theory and Application

2.1 Metabolism

The formal concept of urban metabolism is primarily traced back to Abel Wolman (a sanitary engineer), who in 1965 published a seminal paper titled “The Metabolism of Cities” (ABEL 1965). In this paper, Wolman conceptualized cities in analogy to living organisms, analyzing them in terms of input (water, food, fuel, and raw materials) and output (solid waste, sewage, and other emissions). His goal was to quantify the flows of materials and energy required to sustain urban life, providing a framework for understanding the impact of urban development on resource consumption and waste generation. Thus, the original origins of urban metabolism as a theory and field of study are deeply rooted in environmental engineering as a systems foundation for city planning.

Certainly, in the usage of the term metabolism and the idea of human and non-human flows these ideas have been studied prior to Wolman’s work. This history is further expanded in its origins and history of the ideas within the paper, “The boundaries of urban metabolism: Towards a political–industrial ecology” (NEWELL et al. 2014). Over time, the concept has evolved to incorporate broader considerations, including social, economic, and ecological aspects, but its core remains focused on analyzing and optimizing the flows of resources and waste within urban systems.

Inputs and outputs in systems modelling provide a framework for understanding and optimizing the complex interactions involved in landscape development. This approach helps ensure that the development is sustainable, cost-effective, and aligned with environmental and social goals. For instance, by modelling water flow and usage, engineers can design efficient irrigation systems that minimize waste and support plant life with varying water needs. Further exhibited in the ideas of “Sewer Mining” in the ideas from Stanford Professor, Craig Criddle, in his 2011 CIFE talk at Google in which any aspect of a waste stream can be broken down and reconstructed to its potential value proposition (CRAIG 2011).

Urban metabolism applies the concept of systems modelling to analyze the flow of materials and energy within cities, viewing them as living organisms that consume resources (inputs) and generate waste and emissions (outputs). It helps in understanding and optimizing how a city functions, by mapping resource consumption and waste production, to develop more sustainable and efficient urban landscapes. Essentially, it's a macro-scale application of systems modelling to improve the sustainability and livability of urban environments.

In their examination of urban metabolism literature, Newell and Cousins identify three main ecological perspectives: Marxist ecologies, which view urban metabolism as a process that produces unequal social and environmental outcomes; industrial ecology, which focuses on the material and energy flows; and urban ecology, which considers cities as com-plex socio-ecological systems. The “Industrial Ecology” perspective, with its emphasis on quantifiable material and energy flows, aligns closely with the methodologies used in Eco-Circuit and the discussed paper. Currently, with the initial development of the Large Language Model (LLM) and the toolset, there is a direct comparison to everyday resource modelling such as water balance, solid waste generation, and organic compost needs within typical civil and environmental engineering practices. Integrating these industrial-type equations into a broader model has been a practical approach in the early stages of *EcoCircuit*’s structure.

2.2 Large Language Model (LLM)

Language Models Reasoning and Refinement Strategies

Text2Flow is inspired by the remarkable progress in complicated problem-solving capabilities of language models attributed to the emergent reasoning and refinement strategies. Central to the approach adapted by *EcoCircuit*, is the Chain-of-thoughts methodology (WEI et al. 2022), which utilizes a series of intermediate reasoning steps to improve model performance. Additionally, various reasoning refinement strategies have been developed to enable LLMs to iteratively refine its outputs and leverage it to enhance its predictions for more complicated tasks. For instance, Tree-of-Thoughts (YAO et al. 2022), extends the CoT method by prompting language models to navigate through coherent units of text (thoughts), facilitating more branched and diverse intermediate steps towards problem serving. Chameleon (LU et al. 2022) addresses the LLMs' limitations in accessing up-to-date information by sequencing a series of tools such as web search engines, heuristic-based modules, to execute to generate the final response. Similarly, the Automatic Reasoning and Tool-use (ART) framework enhances the problem-solving capabilities of Large Language Models (LLMs) by automating intermediate reasoning and incorporating external tool outputs. By selecting and pausing for tool use during tasks, ART effectively integrates complex reasoning steps, showcasing its adaptability and efficiency in extending LLM applications. These methodologies provide valuable insights for *EcoCircuit* on leveraging the responses from various stages, to optimize and generate potential metabolic inspirations. This process of leveraging stage-specific responses allows for a more targeted and informed decision-making pathway, ultimately leading to the formulation of strategies that are well-suited to foster optimal metabolic environments.

LLM-Empowered GUI for Creative Ideation and Iteration

LLMs have been instrumental in enhancing interactive applications across domains such as human-computer interaction and human-robot interaction because of its rapid iterations and self-refinement capabilities. These interactions have become essential in the iterative processes of landscape architecture, a discipline that thrives on continuous idea generation and refinement. At a fundamental level, conversational agents such as ChatGPT and Midjourney has already empowered landscape architects to communicate ideas through languages, facilitating iterative refinements of ideas. This iterative approach has been expanded to applications with enhanced text-visual integration. For instance, TaleBrush (CHANG et al. 2022), is a generative tool for story ideation that combines line sketching with a GPT-based language model to guide the development of a protagonist's journey in collaborative storytelling. Stylette (KIM et al. 2022), enables users to alter web designs using natural language commands, with LLMs inferring the corresponding CSS properties. In the realm of physical applications, SayCan (AHN et al. 2022) harnesses the inherent knowledge within LLMs to fulfil complex, real-world robot commands. *EcoCircuit* leverages the graphic user interface (GUI) by integrating Create, Read, Update, and Delete (CRUD) functionalities, creating a dynamic environment where ideas can be recursively tested in text and visual form, evaluated, and refined, enhancing both the efficiency and potential creativity in the design process.

3 *EcoCircuit* LLM Application Framework

EcoCircuit framework (Fig. 2) entails intricate interplay between user inputs, stages of prompts and user interface. Purple indicates the staged prompts and their corresponding returns used to decipher environmental metabolism concepts. Yellow highlights user interactions within the *EcoCircuit* application, and green indicates the processes to convert returns into a database containing flows and nodes and display them on the interface. *EcoCircuit* employs two core types of pre-trained language models: GPT-3.5-turbo/GPT-4[1] as the text processing model ***M*** and GPT4V(ision)[2] as the visual question answering (VQA) model ***V***.

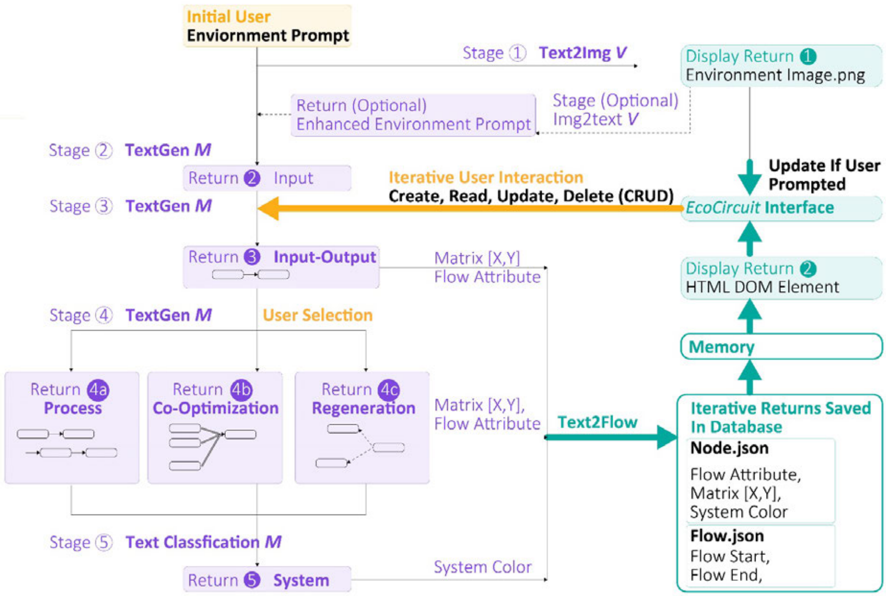

Fig. 2: Framework overview of *EcoCircuit* Application

3.1 Staged Prompts to Decipher Environment Metabolism

Staged prompts are designed to generate fundamental concepts of environment metabolism, such as input, output, process, co-optimization, regeneration/feedback, and system. Meaningful return at each stage is ensured through prompt-engineering strategies, primarily few-shot learning, where models learn from a small set of examples and are complemented by data processing methods, including data cleaning, search, and sort algorithms. In this paper, we focus on staging prompts for visual problem-breaking of environment metabolism. The data processing methods will only be briefly mentioned.

Visual Breakdown of Metabolism Flow Visuals

The flow visualization of environment metabolism (Fig. 1) typically includes critical concepts such as 1) **input and output**, which are color-coded sequenced nodes. Inputs refer to

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[1] Experiments used in this paper were done between Oct 2023 – Feb 2024.
[2] Experiments used in this paper were done between Oct 2023 – Feb 2024.

the resources or elements introduced into the site metabolism, while outputs are the products or results; 2) **system**, indicated by the color-coding of each node, such as hydro, energy, bio-system, transportation, food, economy, etc.; 3) **process**, depicted by lines moving in a positive direction, representing the transformation from input to output; 4) **co-optimization** that is represented by multiple nodes leading to potential shared outputs; 5) **regeneration/feedback** represented by arrows pointing backward shows that outputs of the metabolism can loop back as inputs or intermediate nodes, signifying the recycling or renewal of resources.

Stage 1 Text2Img Prompt: Environment Image

The stage takes the initial user input – a textual environment description and prompts ***V***. The image is returned and displayed as the background reference for conceptualizing the environment (Fig. 3a background).

Stage (Optional) Img2Text Prompt: Enhanced Environment Description

To ensure that user-provided environment descriptions are adequately detailed for subsequent stages and not too brief (fewer than 50 words), *EcoCircuit* features an optional step that enhances these descriptions. In this stage, the environment image generated in stage 1 (Fig. 3a) is presented to the VQA model (V). This model then describes what is in the image, typically 150 to 300 words, to provide a more comprehensive understanding of the environment.

Stage 2 TextGen Prompt: Input

This stage takes the initial user texts or the enhanced texts from the previous optional stage as the environment description (bold text). Then environment description is prompted to text processing model ***M*** and returns a list of inputs i_n (1).

Prompt content	*{"role": "system", "content": "You are to extract and imagine potential resources in the environment description as keywords. The resources in the environment include potential organisms, chemicals, materials; and they come from various systems, such as hydro, energy, and ecosystem. Please try to imagine n resources"},* *(Few-shot examples…),* *{"role": "user", "content":* ***environment description****}*
Processed Return	$[i_1, i_2, \ldots\ldots, i_n]$

(1)

Stage 3 TextGen Prompt: Input-Output

This stage takes the *n* inputs (bold text) from the previous stage, prompts to model ***M***, and returns $n*m$ input-outputs $[i_n, o_m]$ matrix (2).

Prompt content	*{"role": "system", "content": "Given the input resources, please come up with output resources. These output resources are values and helpful optimize the environmental process to achieve net zero sustainability goals such as net-zero energy, net zero carbon, net-zero water. Please come up with m outputs for each input."},* *(Few-shot examples…),* *{"role": "user", "content":* $\boldsymbol{[i_1, i_2, \ldots\ldots, i_n]}$*}*
Processed Return	*When m =1,* $[[i_1, o_1], [i_2, o_2], \ldots\ldots, [i_n, o_n]]$ *When m >1,* $[[i_1, o_1], [i_1, o_2], \ldots\ldots [i_n, o_m], [i_2, o_1], [i_2, o_1], \ldots\ldots [i_2, o_m], \ldots\ldots, [i_n, o_1], [i_n, o_1], \ldots\ldots [i_n, o_m]]$

(2)

Stage 4 TextGen Prompt: Advanced Metabolism Concepts

Beginning with stage 3, an $n*m$ input-output matrix is displayed (where m equals 1, Fig. 3b, Fig. 4b). *EcoCircuit* initially presents the inputs and outputs of the environment for a preliminary understanding. Users can then explore more advanced landscape metabolism concepts, such as process, co-optimization, and regeneration/feedback mechanisms in stage 4.

4a Process

Assuming a user selects p pairs of input-output, this stage operates as follows: for each selected pair $[i_k, o_k]$ (bold text), model $\boldsymbol{M}$ returns t different methods. Each method m_l is represented as two to five sequenced nodes $[m_{l\text{-}n1}, m_{l\text{-}n2}, m_{l\text{-}n3}, m_{l\text{-}n4}]$ (3).

Prompt Content – Input-Output Pair k	*{"role": "system", "content": "You are an encyclopaedia. Knowledge consists of m methods of generating the flow. Each method could be processes, resources, and technologies to transform input to output. Please don't make up the knowledge if you don't know it."},* *(Few-shot examples...),* *{"role": "user", "content":* $\boldsymbol{[i_k, o_k]}$*}*
Processed Return – Input-Output Pair k	$[[i_k, m_{1\text{-}n1}, m_{1\text{-}n2}, o_k],$ $[i_k, m_{2\text{-}n1}, m_{2\text{-}n2}, m_{2\text{-}n3}, m_{2\text{-}n4}, o_k],$ *……,* $[i_k, m_{t\text{-}n1}, m_{t\text{-}n2}, m_{t\text{-}n3}, o_k]]$ (3)

4b Co-optimization

Assuming that a user selects q nodes from the interface $[n_1, n_2, ..., n_q]$ (bolded text), each node represents a usable resource within the environment. The selected q nodes may include inputs, outputs, or any intermediate nodes that have emerged from the advanced exploration of the landscape metabolism concepts. Model $\boldsymbol{M}$ then returns w co-optimization scenarios based on those selections. Each co-optimization scenario involves a combination of 2 to 4 nodes out of the q selected, showcasing how different resources can be synergistically integrated for optimized environmental performance (4).

Prompt content	*{"role": "system", "content": "You are to imagine environmental flows by co-optimizing the elements to achieve a sustainable net-zero environment and a circular economy. Given the resources, please try the combination of two to four elements, and imagine what these could co-generate. "},* *(Few-shot examples...),* *{"role": "user", "content":* $\boldsymbol{[n_1, n_2, \ldots, n_q]}$*}*
Processed Return	*i.e., when node 1,2,7 is combined, for co-optimization,* $[[n_1, o_1], [n_2, o_1], \ldots\ldots [n_7, o_1]]$ *i.e., when node 2,5,12 is combined, for co-optimization,* $[[n_2, o_2], [n_5, o_2], \ldots\ldots [n_{12}, o_2]]$ (4)

4c Regeneration/Feedback

Presently, with b nodes $[n_1, n_2, ..., n_b]$ available on the interface, when a user selects a node n_c (bold text) to prompt regeneration, model $\boldsymbol{M}$ is prompted to identify nodes that can be regenerated by node n_c. This stage determines the potential for resource renewal and feedback loops initiated by the selected node within the environmental system (5).

Prompt content – Node c	*{"role": "system", "content": "You are to help me think about regenerative sustainable practices for an environment. Here are the valuable elements [n_1, n_2,…, n_b]in this environment, imagine what can be generated from the provided environment. Don't make up the knowledge if you don't know it."},* *(Few-shot examples…),* *{"role": "user", "content":* ***[n_c]****}*	
Processed Return – Node c	*i.e., when node 1,2,7 is able to be regenerated,* *[[n_c, n_1], [n_c, n_2], [n_c, n_7]]* *i.e., when node 2,5,12 is able to be regenerated,* *[[n_c, n_2], [n_c, o_5], [n_c,o_{12}]]*	(5)

Stage 5 System Prompts

Presently, with b nodes *[n_1, n_2,…, n_b]* (bold text) available on the interface, model ***M*** classifies all nodes into 4 systems: hydro, energy, and bio-system, and unknown (6).

Prompt content	*{"role": "system", "content": "You are an encyclopaedia. Your job is to classify the element. I will give you an element list, and you will classify each element in the list to 'ecosystem', 'energy', 'hydro'. Output 'unknown' if the element cannot be classified. "},* *(Few-shot examples…),* *{"role": "user", "content":* ***[n_1, n_2,…, n_b]*** *}*	
Processed Return	*i.e., if n_1 ,belongs to "hydro", n_2 belongs to "bio-system", n_3 belongs to " hydro", n_4 belongs to " energy", ……, n_b belongs to "unknown",* *{n_1: "hydro", n_2: "bio-system", n_3: " hydro", n_4: "energy", ……, n_b: "unknown"}*	(6)

3.2 Text2Flow Database for Display

In the above stages, returns of stage 3 (input-output), and stage 4 (process, co-optimization, and regeneration) are stored in a list format *[a,b]*(2-5), indicating the directional flows. This information, detailing nodes and flows, coupled with stage 5 (system color) is stored in a database that systematically records data during iterative user interactions and visually displayed on *EcoCircuit* interface as environment metabolism (Fig. 3c, Fig. 4c) (7).

Node.json	*The json file includes Color (Color-Coded System), Matrix [X (Seq In The Flow), Y (Index Of The Flow)]* *i.e. {"Nutritional Supplements": ["Rgb(57, 181, 74)",[1,5]}*	
Flow.json	*The json file includes Flow Start, Flow End, and Flow Stage ("Input-Output" "Process" "Co-Optimization" "Regeneration")* *i.e. {"Input-Output": ["Muddy Soil", "Flood Control"]}*	(7)

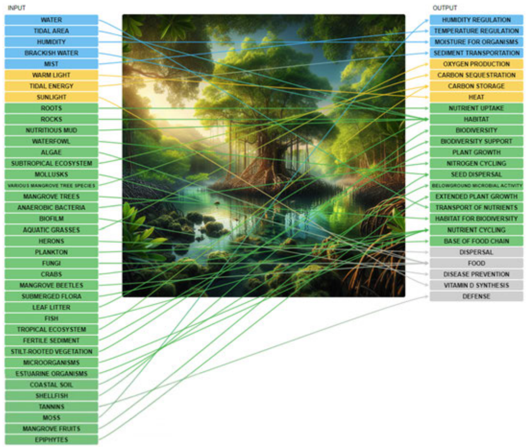
Initial User

"This is a mangrove park."

(a) LLM Enhanced Description

"This image depicts a serene and lush mangrove forest. The central focus is a large mangrove tree with its distinctive stilt-like roots emerging from the water, supporting a dense canopy of green leaves. Sunlight filters through the foliage, casting a warm glow and illuminating the scene. The water is calm and clear, revealing submerged moss-covered roots and rocks beneath the surface, which adds to the depth and complexity of the ecosystem. Various mangrove tree species with their tangled root systems are visible throughout the image, creating a sense of wild, natural beauty. There's a soft mist in the background suggesting humidity typical of mangrove forests, which are often found in tropical and subtropical tidal areas. The sunlight suggests it might be either morning or late afternoon when the light is soft and warm. The image is rich in detail and has an almost magical quality to it, highlighting the tranquil and mysterious nature of this unique ecological environment."

(b) Interface after Stage 3 TextGen Prompt: Input-Output



User Selection Selected flows for processes: "water" to "transport of nutrients," "roots" to "nutrient uptake," "waterfowl" to "seed dispersal," "submerged flora" to "nutrient cycling," "fertile sediment" to "plant growth"; selected nodes for co-optimization "tidal area," "nutritious mud," "herons," "fungi," "leaf litter," "microorganisms"; selected node for regeneration/feedback: "plant growth."

(c) Interface after Stage 4 Advanced TextGen Prompt: Process(solid), Co-optimization (double-line outline), Regeneration/feedback (dash line)

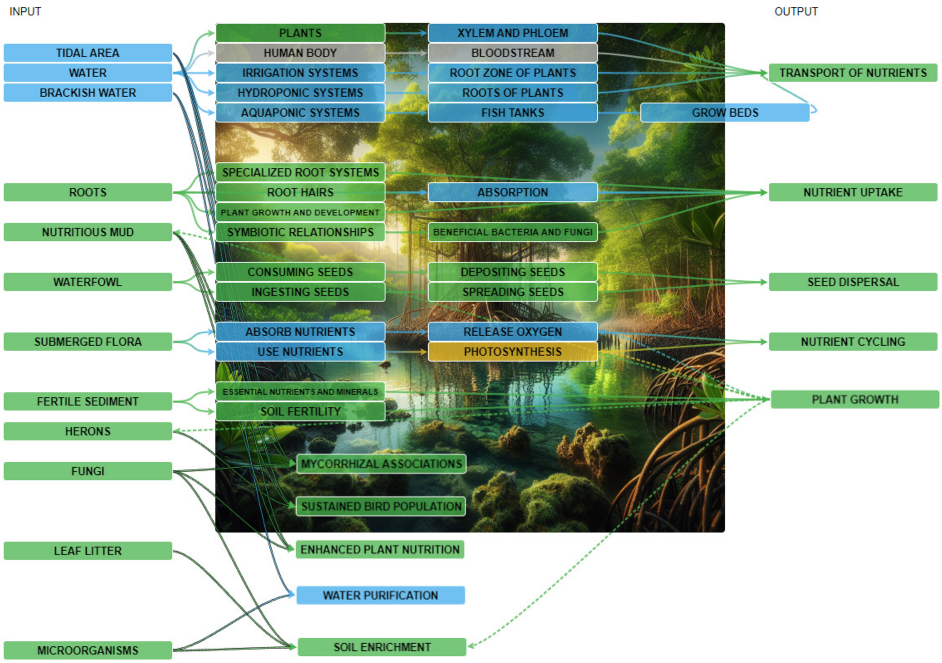


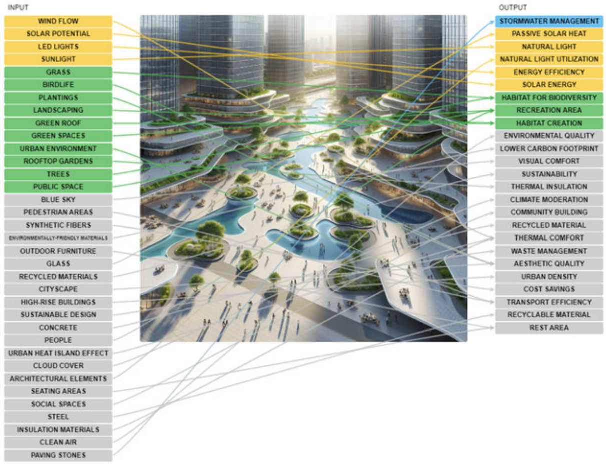
Fig. 3: *EcoCircuit* test case in a mangrove park setting

Initial User

"The campus plaza is a showcase of parametric design and environmental technology. Its pavements display complex, flowing patterns, crafted through parametric modeling to optimize foot traffic flow and integrate advanced drainage systems. Seating areas, ergonomically designed using data and made from recycled materials, encourage social interaction while blending seamlessly into the design."

(a) LLM Enhanced Description
N/A

(b) Interface after Stage 3 TextGen Prompt: Input-Output



User Selection Selected flows for processes: "wind flow" to "thermal comfort," "rooftop garden" to "thermal insulation," "cloud cover" to "climate moderation," "paving stones" to "stormwater management"; selected nodes for co-optimization "birdlife," "green spaces," "pedestrian areas," "recycled materials"; selected node for regeneration/feedback: "stormwater management," "climate moderation."

(c) Interface after Stage 4 Advanced TextGen Prompt: Process (solid line), Co-optimization (double-line outline), Regeneration/feedback (dash line)

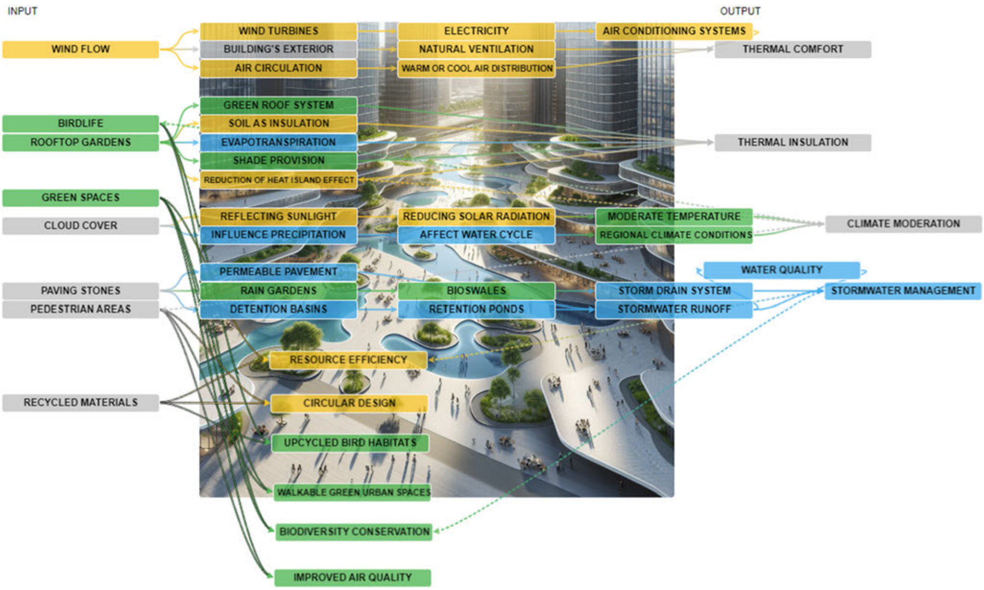


Fig. 4: *EcoCircuit* test case in an urban plaza setting.

Initial User

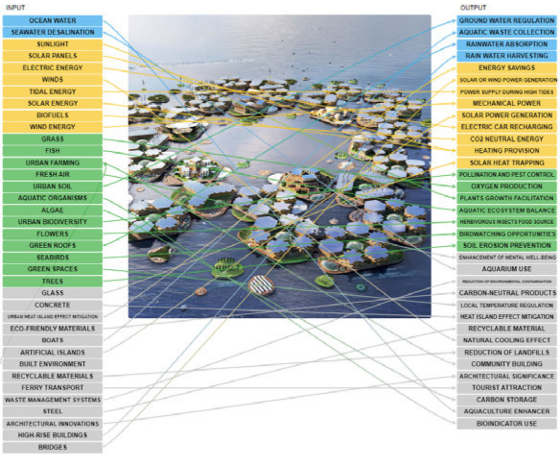
“Thes are floating islands.”

Uploaded published project image.

(a) LLM Enhanced Description

“The image depicts an expansive and futuristic water-based community or city. Individual platforms with a variety of structures, greenery, and interconnected paths float on the surface of the water. The platforms seem to be arranged in a roughly circular formation, creating a kind of archipelago of habitable, interconnected islands.On these platforms, you can see an array of modern and sustainable buildings outfitted with what appears to be solar panels. There is lush vegetation interspersed throughout the area, with trees and lawns. Several platforms feature agricultural spaces, suggesting an emphasis on local food production and self-sufficiency. Recreational areas with what appear to be lounging spaces and swimming pools can be spotted as well. The community is peppered with small boats and watercraft, indicating that transportation between the platforms relies on aquatic transit. Overall, the design seems to prioritize sustainability, modern living, and harmony with the aquatic environment, suggesting a response to rising sea levels or a novel approach to urban planning on water.”

(b) Interface after Stage 3 TextGen Prompt: Input-Output



User Selection Selected flows for processes: “ocean water” to “aquaculture enhancer,” “solar panels” to “heating provision,” “tidal energy” to “power supply during hide tides,” “wind energy” to “mechanic power”; selected nodes for co-optimization “urban farming,” “algae,” “seawater desalination,” “waste management system,” “solar or wind power generation,”; selected node for regeneration/feedback: “mechanical power.”

(c) Interface after Stage 4 Advanced TextGen Prompt: Process (solid line), Co-optimization (double-line outline), Regeneration/feedback (dash line)

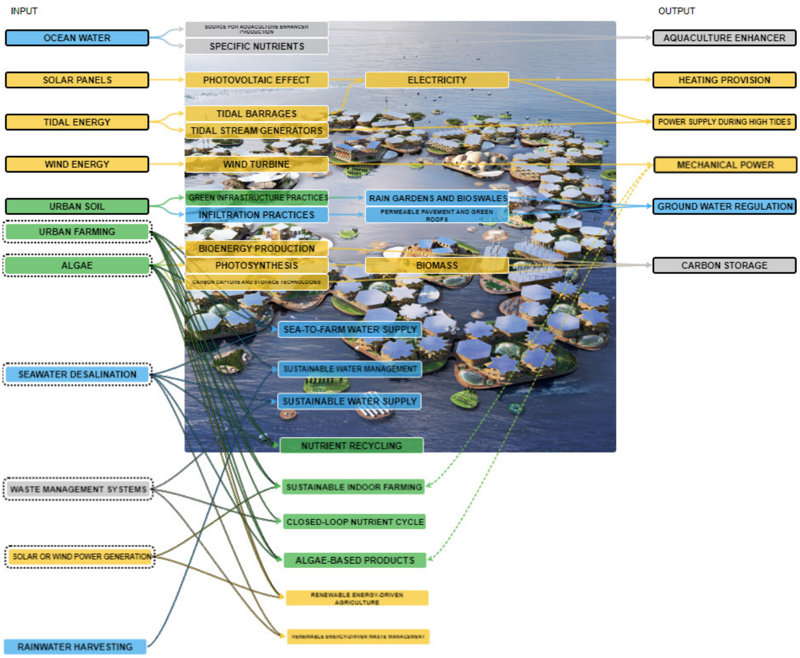


Fig. 5: *EcoCircuit* test case with Oceanix Busan by BIG Bjarke Ingels Group

Initial User

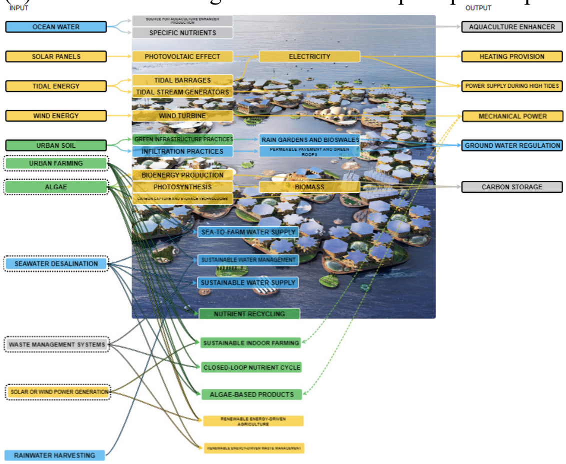
"This is a port city."

Uploaded published project image.

(a) LLM Enhanced Description

"The conceptual rendering of Rotterdam in the image presents a comprehensive urban ecosystem. The waterways are bustling with cargo ships, signifying a thriving trade hub. Energy infrastructure, possibly indicated by turbines or solar panels, underscores a commitment to renewable resources. Sandbanks and sediment management appear to be integrated into the landscape, hinting at innovative dredging solutions. Floating structures could represent aquaculture or hydroponic systems, suggesting a sustainable approach to food production. Waste management is likely envisioned through eco-friendly disposal and recycling systems, although specific facilities are not distinctly visible. This future vision of Rotterdam encapsulates a symbiotic relationship between industrial progress and environmental stewardship."

(b) Interface after Stage 3 TextGen Prompt: Input-Output



User Selection Selected flows for processes: "sand banks" to "wildlife sanctuary," "agricultural plots" to "soil nutrient renewal," "waste processing system" to "material recycling," "cargo ship" to "waste heat recovery for propulsion," "ship metals" to "fabrication materials," "smokestacks" to "carbon sequestration"; selected nodes for co-optimization "river silt," "plastic waste," "waterways," "renewable energy," "wind turbines," "agricultural plots," "urban farming," "economic stimulus" "cargo ships"; selected node for regeneration/feedback: "soil nutrient renewal," "material recyling."

(c) Interface after Stage 4 Advanced TextGen Prompt: Process (solid line), Co-optimization (double-line outline), Regeneration/feedback (dash line)

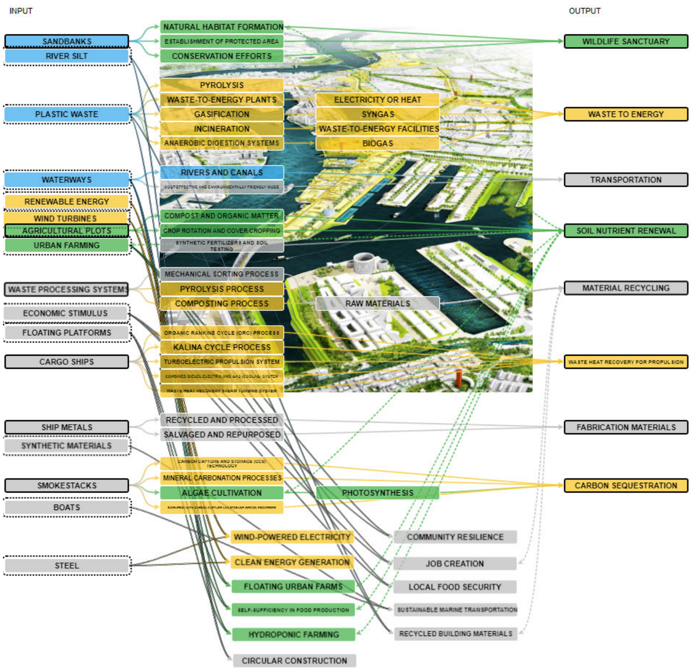


Fig. 6: *EcoCircuit* test case with Rotterdam Landscape by Field Operations

3.3 Iterative User Interaction (CRUD)

To enhance adaptability and flexibility in design iterations, the *EcoCircuit* application incorporates a Create, Read, Update, and Delete (CRUD) interface, crucial for dynamic design processes. The interface allows users to continuously refine and evolve their landscape metabolism models. It includes the below functions: 1) **Create**: Users can introduce new nodes and flows to the environment metabolism design; 2) **Read**: This function enables users to visualize complex metabolism information in real-time iterations; 3) **Update**: Users can modify AI-generated nodes within the model, reshape flows, or alter node properties to align with changes in design concepts, thereby enhancing AI and human collaboration; 4) **Delete**: This feature allows users to remove elements that are no longer relevant or necessary in their design, ensuring the design remains current and focused.

4 Feasibility Experiment

As shown in Fig. 3, 4, 5, 6, we demonstrate the feasibility of using LLMs to generate metabolism drawings via a GUI (Graphic User Interface) through experiments with various settings, conceptual environments and published projects. The experiments utilize GPT-3.5 and GPT-4 models, which have a maximum context window of 8192 tokens[3] (OPENAI, 2023). Despite the application of various data processing strategies aimed at augmenting complexity, this constraint predominantly accounts for the uniformity observed in the output graphic complexity across distinct experimental settings.

For both conceptual environments and published project test cases, the evaluation metrics include the following: 1) **flow correctness**, determining the factual accuracy; 2) **flow environmental relevance**, assessing the extent to which the metabolic flows generated are reflective of the described environment; 3) **element system correctness**, which accesses the accuracy with which nodes are classified into environmental systems such as hydro, energy, and ecosystem. Additionally, for the published projects, a **comparative analysis** is included to examine how well the *EcoCircuit* results match the metabolic diagrams drawn from these projects, using the latter as a baseline for comparison (Tab. 1).

We conducted evaluations on 45 metabolism generations within various settings. These generations include 40 conceptual environments such as a mangrove park, urban plaza, high-tech campus, the moon, an underwater city, etc, along with three published landscape projects. As various data processing methods apply, these metrics are not an evaluation of the improved model capacity, but a feasibility study of the Text2Flow framework. The result (Tab. 2) indicates an approximate accuracy of 95% for both flow correctness and node system correctness. These figures closely match the benchmark accuracy of 95.3% established by GPT4 for 10-shot examples[4] in commonsense reasoning about everyday events (OPENAI, 2023). It is to note that with CoT reasoning strategies applied to metabolism generations, as

[3] Tokens are the basic units of data processed by large language models, which are usually pieces of texts. The exactly length of the text pieces varies by models.

[4] Few-shot prompting involves providing a small number of examples (shots) to guide a language model to perform specific tasks or generate desired responses. “10-shot examples” indicates 10 examples.

the complexity of generation increases, the accuracy of results still remain. In terms of flow environment relevance, it slightly decreases in further stages, from above 95% to the lower ranges. The average of 91.8% is valuable for potential applications.

Despite the high rate of flow correctness, flow environmental relevance, and node system correctness showing the feasibility of the *EcoCircuit*'s Text2Flow approach, the comparative analysis between *EcoCircuit* results and the metabolism flow textual contents indicates a low correlation (Tab. 2), with a correlation of less than 25%. In the case of the evaluation on three published projects, further additional test cases are suggested for a more accurate result. Even that, based on the observations of these limited alignments, we identified three major factors contributing to the discrepancy. Firstly, AI results tend to be generic, whereas human-created solutions feature more specific components; Secondly, to capture the full scope of design considerations from the provided environmental description and project images proved challenging, highlighting the importance of continuous input for refining results. Thirdly, our findings suggest that the optimal application of this tool lies in facilitating creativity and brainstorming during the initial stages of design, rather than as a means of generating finalized products for designers.

5 Discussion

The proliferation of Large Language Models (LLMs) and AI tools signifies a major advancement in unravelling complex dynamics and hidden information within landscape architecture design. *EcoCircuit*, a Text2Flow application, provides a visual problem-breaking and reasoning method for deciphering landscape complexity through environmental metabolism. The staged returns from the LLMs enable rapid iteration and refinement of metabolism flow visualization. We have identified four key points of discussion:

1) **Importance of domain-specific LLMs for landscape architecture**: While LLMs exhibit remarkable reasoning capabilities, their effectiveness as "generalists" is limited. Through qualitative assessment of the metabolism graphic indicates that flows produced in stage 4 tend be generic. This generality presented a potential challenge for the effective implementation of the framework. The LLMs utilized in this project, Open AI's GPT series, trained on diverse internet texts such as books and websites, could benefit from fine-tuning for landscape-specific topics.

2) **Visual problem breaking for deciphering complexity in landscape architecture**: Visual representation effectively imparts information with methods like diagrams, infographics, and narratives, each having a role in storytelling (MANNING, 2011). Utilizing LLMs/AIs to deconstruct and reconstructs informational visuals promotes efficiency and ideation in design processes.

3) **Future incorporation of metrics parameters in landscape metabolism**: A notable gap in the quantitative aspect of landscape metabolism, typically reflected in the relative sizes of nodes and flow arrows, is not covered in this paper's study. Leveraging the data analysis capabilities of LLMs, future developments could introduce metrics to enhance the understanding and representation of landscape metabolism.

4) **Iterative human and AI collaboration**: Human involvement in overseeing AI processes is vital. Since AI systems base their decisions on their training data, they often

struggle with new, unencountered situations. By integrating human interactions (CRUD) with AI's analytical power, we can achieve more practical, innovative, and adaptable solutions.

Table 1: *EcoCircuit* evaluation example with Oceanix Busan by BIG Bjarke Ingels Group

Baseline Reference (Optional for conceptual environment test cases)		**EcoCircuit Result**			
Ref. Seq	**Metabolism Textual Content (Content extracted from Fig.1 Bottom Right Oceanix Busan City System Diagram)**	**Match Seq. (Optional)**	**Stage 3 Input-Output (Content extracted from Fig.5b, 5c, EcoCircuit rerun test of Oceanix Busan)**	**Flow Correctness T=True F=False**	**Environment Relevance T=True F=False**
1	Algae Bioreactor --> Compost Garden		Artificial Islands --> Solar Power Generation	T	T
2	Algae Filtration --> Algae Biogas	2	Algae --> Carbon Storage	T	T
3	Algae Filtration --> Non-Potable Water Storage		Aquatic Organisms --> Bioindicator Use	T	T
4	Atmospheric Wate Collector --> Potable Water Storage		Architectural Innovations --> Architectural Significance	T	T
5	Bathroom --> Algae Filtration		Biofuels --> CO2 Neutral Energy	T	T
6	Bathroom --> Treatment Swale		Boats --> Aquatic Waste Collection	T	T
7	Cool Water --> Heat Exchange		Bridges --> Solar or Wind Power Generation	T	T
8	Current --> Generator		Built Environment --> Urban Farming	T	T
9	Dehumidifier --> Non-Potable Water Storage		Concrete --> Heat Island Effect Mitigation	T	T
10	Deployable Water Bladder --> Non-Potable Water Storage		Eco-Friendly Materials --> Carbon-Neutral Products	T	T
11	Energy Storage --> Aeroponics		Electric Energy --> Electric Car Recharging	T	T
12	Energy Storage --> Aquaponics		Ferry Transport --> Tourist Attraction	T	T
13	Energy Storage --> Electricity		Fish --> Aquatic Ecosystem Balance	T	T
14	Food Waste Collection --> Anaerobic Digester		Flowers --> Herbivorous Insects Food Source	T	T
15	Food Waste Collection --> Fertilizer		Fresh Air --> Enhancement Of Mental Well-Being	T	T
16	Fertilizer --> Outdoor Farm		Glass --> Solar Heat Trapping	T	T
17	Generator --> Energy Storage		Grass --> Oxygen Production	T	T
18	Heat Exchange --> Exchange Hub	4	Green Roofs --> Rainwater Absorption	T	T
19	Heat Exchange --> Fan		High-Rise Buildings --> Rain Water Harvesting	T	F, high-rise building irrelevant
20	Humidity --> Atmospheric Water Collector		Ocean Water --> Aquaculture Enhancer	T	T
21	Laundry Chute --> Washing Center	32	Recyclable Materials --> Reduction of Landfills	T	T
22	Non-Potable Water Storage --> Indoor Farm		Seabirds --> Birdwatching Opportunities	T	T
23	Non-Potable Water Storage --> Potable Water		Seawater Desalination --> Aquarium Use	T	T
24	Non-Potable Water Storage --> Washing Center		Solar Energy --> Heating Provision	T	T
25	Offgrid Wind Turbine --> Compressed Energy Storage		Solar Panels --> Heating Provision	T	T
26	Offgrid Wind Turbine --> Wave Energy Converter		Steel --> Recyclable Material	T	T
27	Potable Water -->Graywater Treatment	39, 40, 41	Sunlight --> Plants Growth Facilitation	T	T
28	Potable Water Storage --> Potable Water	44	Tidal Energy --> Power Supply During High Tides	T	T
29	Rain --> Dehumidifier		Trees --> Soil Erosion Prevention	T	T
30	Rain --> Outdoor Farm		Urban Biodiversity --> Pollination and Pest Control	T	T

Table 1 (continued)

31	Rain --> Public Realm Collection		Urban Farming --> Community Building	T	T
32	Recycling --> Sorting		Urban Heat Island Effect Mitigation --> Energy Savings	T	T
33	Returns Chute --> Sorting		Urban Soil --> Ground Water Regulation	T	F, ground water is not relevant
34	Renewable Desalination --> Potable Water Storage		Waste Management Systems --> Reduction of Environmental Contamination	T	T
35	Reusable Dropoff --> Washing Center	47	Wind Energy --> Mechanical Power	T	T
36	Roof Collection --> Non-Potable Water Storage		Winds --> Natural Cooling Effect		
37	Salt Water --> Renewable Desalination		**Stage 4a Co-Optimization**	T	T
38	Sun --> Algae Bioreactor		Seawater Desalination + Waste Management --> Renewable Energy-Driven Waste Management	T	T
39	Sun --> Indoor Farm		Seawater Desalination + Waste Management Systems --> Sustainable Water Supply	T	T
40	Sun --> Outdoor Farm		Urban Farming + Algae + Seawater Desalination --> Algae-Based Product	T	T
41	Sunlight --> Indoor Farm		Urban Farming + Algae + Seawater Desalination --> Nutrient Recycling	T	T
42	Warm Water --> Heat Exchange		Urban Farming + Algae + Seawater Desalination --> Sea-To-Farm Water Supply	T	T
43	Wastewater Treatment --> Non-Potable Water Storage		Urban Farming + Algae+ Solar or Wind Power Generation --> Renewable Energy-Driven Agriculture	T	T
44	Waves --> Wave Energy Converter		Urban Farming + Algae+ Solar or Wind Power Generation --> Sustainable Indoor Farming	T	T
45	Wind --> Offgrid Wind Turbine		Urban Farming + Rainwater Harvesting --> Sustainable Water Management	T	T
46	Wind --> Wind Turbines		Urban Farming + Waste Management System --> Closed-Loop Nutrient Cycle	T	T
47	Wind Turbines --> Energy Storage		**Stage 4b Process**		
			Ocean Water --> Source for Aquaculture Enhancer	T	T
			Ocean Water --> Specific Nutrients	T	T
			Solar Panels --> Photovoltaic Effect --> Electricity --> Heating Provision	T	T
			Tidal Energy --> Tidal Barrage --> Electricity --> Power Supply During Hide Tides	T	T
			Tidal Energy --> Tidal Stream Generators --> Power Supply During Hide Tides	T	T
			Urban Soil --> Green Infrastructure Practices --> Rain Gardens And Bioswales --> Groundwater Regulations	T	F, ground water is not relevant
			Urban Soil --> Infiltration Practices --> Permeable Pavement and Greenroof --> Groundwater Regulations	T	F, ground water is not relevant
		45, 46	Wind Energy --> Wind Turbine --> Mechanic Power	T	T
			Stage 4c Feedback		
			Mechanical Power --> Algae-Based Product	T	T
		11, 12	Mechanical Power --> Sustainable Indoor Farming	T	T

Table 2: *EcoCircuit*'s basic metrics evaluation results

Test Objectives	Flow Correctness	Flow Environmental Relevance
Stage 3 Input-Output	96.9%	96.7%
Stage 4a Process	95.2%	91.7%
Stage 4b Co-optimization	93.8%	84.1%
Stage 4c Feedback	95.7%	94.7%

Test Objective	Node System Correctness
Nodes	97.4%

6 Conclusion and Outlook

Deciphering environment metabolism through *EcoCircuit* demonstrates the potential of integrating AI/LLMs in landscape-specific applications. *EcoCircuit*'s emergence aligns with the increasing need for complex thinking in landscape architecture in a world of changing climate and resilience. *EcoCircuit* deconstructs metabolism visuals, offering generative understandings of fundamental environmental metabolism concepts such as input, output, processes, co-optimization, regeneration, and system. Looking ahead, tools like *EcoCircuit* are set to become increasingly crucial for unravelling complex environmental information and addressing intricate concepts like time management, dynamics, metrics, and performance. *EcoCircuit* explores the creative processes with LLMs and actualizing effective human-AI collaboration in landscape architecture.

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