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# Transformative urban design: a case study of bio-inspired urban photobioreactor Liquid3

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This mini-review presents a case study of an urban photobioreactor Liquid3, which combines microalgae-based air purification with multifunctional urban design to demonstrate the transformative role of bio-inspired techno-environmental innovations. Liquid3 is a public installation designed in accordance with the principles of efficient urban land use, aiming to deliver environmental, social, and economic benefits while addressing key challenges of urban environmental management. Drawing on a transdisciplinary approach, Liquid3 integrates scientific, design, and social perspectives, functioning not only as a technology for CO<sub>2</sub> and particulate matter reduction but also as a driver of societal engagement. The transformative urban design of the Liquid3 photobioreactor fosters environmental awareness, encourages active community engagement, and creates potential for educational applications across diverse cultural contexts. Through social media, Liquid3 may serve as a societal catalyst, reshaping public understanding of ecological processes, the role of technology, and the value of urban greenery, while encouraging civic reflection and new imaginaries for sustainable cities. In terms of its educational potential, Liquid3 may function both as a model of economically viable environmental innovation and as a pedagogical tool. Ultimately, this case study underscores the critical role of transformative urban design as a framework for discussing and reimagining sustainable urban futures.

## KEYWORDS

air pollution, biotechnology, education, social networks, techno-environmental, transformative design

## 1 Introduction

The development of bio-inspired technologies and nature-based solutions aimed at redirecting unsustainable trajectories toward just urban transformations relies on transdisciplinary approaches and participatory, collaborative, and action-oriented scientific practices (Frantzeskaki et al., 2025; Mesa-Jurado et al., 2025). Transdisciplinary initiatives grounded in co-creation among scientists, artists, decision-makers, and societal actors ensure the development of contextually appropriate solutions, while also promoting new relational dynamics, transformative actions, and imaginative pathways toward more sustainable futures. Such initiatives emphasize participatory visioning, storytelling, and aesthetic engagement, contributing to holistic transformations beyond traditional disciplinary boundaries (Gallois et al., 2024; Mesa-Jurado et al., 2025). In this context, they should offer more than technical solutions and innovations incorporating transformative design that facilitates and guides societal evolution. Through the productive integration of its elements, transformative design developed through inter- and transdisciplinary

approaches fosters positive interdependence, using design to shift perceptions, encourage dialogue, inspire new actions, and support equity, empathy, hope, and social progress (Benedikter, 2025).

Herein, a case study of the Liquid3 urban photobioreactor is used to demonstrate the role of transdisciplinarity in tackling complex environmental challenges and the development of bio-inspired solutions, as well as to illustrate the practical potential of transformative design, highlighting its social and educational potential. Liquid3 exemplifies a bio-inspired technological solution for urban air pollution that integrates microalgae-based biotechnological functions with urban design (Figure 1). It has been developed from concept to prototype at the University of Belgrade—Institute for Multidisciplinary Research, within the framework of UNDP Serbia project “Climate-Smart Urban Development,” which has aimed to support innovative and smart city solutions for urban air pollution. Intensively used urban zones, such as commercial, administrative, and cultural centers, often experience high levels of air pollution combined with limited space for greenery, making cities particularly vulnerable in terms of sustainability (Borck and Schrauth, 2021). The innovative Liquid3 concept exploits high CO<sub>2</sub> capture efficiency of microalgae, their ability to produce O<sub>2</sub> and biomass, and their capacity to sequester heavy metals from particulate matter (PM). Drawing on the principles of efficient urban land use while generating social, economic, and environmental benefits for local communities, Liquid3 team has developed an innovative solution for urban environmental management. This mini-review demonstrates how the transformative urban design of Liquid3 photobioreactor fosters environmental awareness, community engagement, and educational opportunities. Since the installation of the first unit in Belgrade in 2021, Liquid3 has generated tremendous public, media, educational and commercial interest and has contributed to the emergence of the term “liquid tree,” now used to denote any microalgae-based air purifying system.

## 2 Transformative urban design

Public spaces, intended to serve as equitable and inclusive environments, face growing pressures from environmental degradation, limited greenery, and overcrowding. Air pollution, driven by dense populations and intensive urban activities, cannot always be mitigated by traditional vegetation (e.g., trees and lawns) due to spatial constraints, high land values, and severe soil and air pollution. Uneven greenery and poor air quality threaten both quality of life and urban sustainability (Calderón-Garcidueñas and Villarreal-Ríos, 2017; Du and Zhang, 2020). Therefore, the critical redesign of public spaces is essential to promote environmental sustainability and the wellbeing of urban communities. Motivated by this challenge, a multidisciplinary team of biologists and an architect designed Liquid3 photobioreactor, an innovative urban installation that purifies the air while also providing multiple urban functions. The development of bio-inspired solutions depends on a comprehensive understanding of the context and requires a shift toward epistemological inclusivity (Frantzeskaki et al., 2025).

Design, planning, and implementation call for a transition from multidisciplinary approaches (collaboration without integration), to interdisciplinarity (integration and mutual influence), and ultimately to transdisciplinarity (further engagement with society, policymakers, and the commercial sector) (Alvargonzález, 2011; Butt and Dimitrijević, 2022). By integrating microalgae-based biotechnology into public urban space, the team behind Liquid3 combined expertise in design, humanities, and natural and technical sciences and embodied an art–science approach to urban design. The concept was developed into a fully functional prototype through collaboration with engineers, sustainability and environmental experts, local government, UNDP and other funders, and PR and media specialists, fulfilling the principles of transformational sustainability science that emphasizes co-creation and partnerships among diverse stakeholders in addressing real-world challenges (Brandt et al., 2022). From the outset, public engagement was ensured through media, social networks, direct interactions (expos, lectures, presentations, correspondence), and a public vote that was applied in the selection of Liquid3 installation sites based on citizens’ perceptions of the most air-polluted urban areas in Serbia.

The development of the concept required addressing biological aspects, design, and social engagement (Figure 1). Despite their high CO<sub>2</sub> capture and O<sub>2</sub> production potential (Wang et al., 2008), and their significant potential for innovative environmental engineering solutions (Sahu et al., 2025), microalgae have remained largely overlooked in efforts to mitigate climate change, primarily due to the practical challenges of large-scale application posed by their aquatic habitat. Although various photobioreactor systems for commercial microalgal biomass production are widely available, they are highly specialized and unsuitable for urban applications. This highlights a critical gap and the need for transdisciplinary collaboration to promote the widespread adoption of these systems in everyday urban contexts. Placing microalgae “on the street” required synergy between architecture and biosciences to integrate functional performance of microalgae, aesthetic design, and public usability. The Liquid3 design integrates flat-panel and airlift bioreactor principles into a glass tank mounted on a steel structure with embedded electrical and airflow systems with power consumption of 100 W. It was engineered for urban durability and ease of installation and maintenance, while serving as air purifier and multifunctional smart bench. Liquid3 was built to operate in all climates, including desert and sub-zero temperatures. The former is particularly important, taking into account the multi-layered problem of greenery in MENA and similar climatic regions. The same cosmopolitan strain of microalgae (eukaryotic unicellular algae), which is thermo- and light-tolerant and fast-growing, is employed across all climatic conditions due to its wide thermal tolerance, growing at temperatures between 5 and 45 °C and surviving temperatures of up to 55 °C. For regions with sub-zero temperatures, the glass tank is equipped with microheaters to prevent freezing, increasing power consumption by an additional 300 W. Liquid3 uses additional LED lighting, which supports algal growth and also serves both decorative and functional purposes as nighttime illumination, without the need for intensity control. The system requires minimal effort and operational cost for routine maintenance, which involves



Biological aspect



Design



Social engagement



FIGURE 1

The key aspects in the development of the concept of Liquid3. Photos and the micrograph are part Liquid3 LLC archive. Source of the bottom right photo: UNDP Serbia. Reproduced with permission.

a monthly intervention of approximately 1.5 working hours, including the replacement of 550 L of water and the addition of solid growth medium for microalgal culture. In contrast to

other air purifying systems, Liquid3 generates biomass as by-product (0.5–1 kg per month), which can be further used as a biofertilizer. The remaining volume of microalgal culture in the

tank at maintenance serves as an inoculum for the next cycle. For improved performance of the system in regions with high insolation, the frequency of maintenance can be increased up to twice per month. The performance of Liquid3 has been tested in all seasons and in three different countries—Serbia, Uzbekistan and Qatar. According to average CO<sub>2</sub> removal rate of 2–3.5 kg per month (Liquid3 LLC Website, 2025), Liquid3 is equivalent to one adult tree or to 200 m<sup>2</sup> of lawns in urban environments (Nowak et al., 2007; Wang and Prominski, 2016). In addition, it removes PM<sub>2.5</sub> and PM<sub>10</sub> particles and sequesters significant amounts of heavy metals. Data collected on three urban locations in Serbia in summer and winter 2025 show that a Liquid3 unit, on average, removed 35 mg of aluminum, 14 mg of strontium, 230 µg of lead, and 180 µg of chromium per month (Dimitrijević et al., 2025). The first Liquid3 unit, installed in the center of Belgrade in September 2021, operates continuously without any malfunctions and has an estimated lifetime of approximately 20 years. About 95% of its mass is composed of steel and glass, making it easily recyclable and contributing to the system's overall sustainability.

The design of Liquid3 was guided by principles of multifunctionality and contextual sensitivity to deliver an urban installation that integrates environmental, social, and aesthetic functions while fostering accessibility, inclusivity, communication, and community interaction (Arruda et al., 2017; Milne and Pojani, 2023). Although installations like Liquid3 play a transformative role in public spaces, they may face resistance when challenging established practices. Public concerns—such as the fear that Liquid3 could replace natural trees—highlight the importance of stakeholder engagement. In communication with the public, it is emphasized that Liquid3 complements, rather than substitutes for living trees, promoting a hybrid approach in which technological and natural systems coexist in the urban environment. The future of sustainable cities lies in designing synergies between organic and artificial systems that enhance both environmental quality and social resilience (Spirn, 1984; Gandy, 2022). In the case of Liquid3, this synergy is literal, as the produced biomass can be used to fertilize a real tree.

### 3 Social relevance

Transformative urban design represents a transdisciplinary, human-centered approach that applies design principles to initiate profound and sustainable change within society. It seeks to address structural socio-environmental challenges by fostering new forms of social engagement, innovation, dialogue, and collective awareness (Nejad et al., 2020). Through this lens, transformative urban design becomes a catalyst for reshaping cultural values, enhancing social justice, and strengthening the resilience and coherence of contemporary cities. Liquid3 represents an urban installation that, whether through its everyday presence or special social events, promotes the values and significance of environmental protection, sustainability, climate change mitigation, and the pursuit of a more livable urban life. Since its first installation, Liquid3 has attracted significant public, media, and business interest, prompting debate on air pollution, the role of technology, ethical implications, and the future of alternative

urban greening concepts. Reports on Liquid3 have been broadcast by Deutsche Welle, Euronews, ZDF, Sky News Australia, Korean Broadcasting System, Die Welt, TV Slovenia, and Radio Television of Serbia, as well as numerous local and regional television stations (Liquid3 LLC Website, 2025), with an estimated overall monthly reach of nearly one billion viewers worldwide. Articles and reports have been published in leading newspapers, such as Newsweek (online edition), and Paris Match, Die Zeit, and Asahi Shimbun (both in paper and online), with over 150 million unique monthly readers, as well as across a wide range of digital platforms such as FOX, ABC, Zoomin, WION, CBS, Weather Channel, Springwise, TechAcute, Science News Explores, and others with an estimate of 400 million unique visitors per month (Figure 2A). The most intensive public debate has taken place on social networks. Leading profiles have featured on Liquid3, including Nas Daily, Pubity, Wealth, Thevarunmayya, SciShow, Breaking Lab, and others. Such public interest has further led in tangible commercial interest from over 500 companies worldwide that contacted Liquid3 LLC start-up (Figure 2B), which further led to the installation of additional Liquid3 units in Serbia, Qatar, Uzbekistan, and Hungary.

To illustrate the social impact, this study presents the main directions of public debate based on a brief qualitative discourse analysis of user-generated comments in response to Nas Daily content on Liquid3, published on YouTube (approximately 7,000 comments; Nas Daily YouTube Page, 2026), Facebook (approximately 7,000 comments; Nas Daily Facebook Page, 2026), and TikTok (approximately 11,000 comments; Nas Daily TikTok Page, 2026). Notably, the posts were shared over 150,000 times. Comment datasets were manually collected from each platform and anonymized by removing usernames and other identifying information. Comments in multiple languages were included; non-English comments were translated prior to analysis to ensure conceptual consistency. A thematic analysis was conducted using iterative close reading—entailing careful examination of the data to capture subtle patterns and meanings—and inductive coding, through which categories were generated directly from the data rather than based on pre-defined codes (Wodak and Meyer, 2009; Braun and Clarke, 2021). By focusing on recurring topics, discursive patterns that show (i.e., the ways in which ideas are communicated), affective registers (capturing the emotional tone of comments), and dominant narratives (representing overarching interpretations constructed by users across platforms), the analysis emphasized qualitative depth, contextual meaning, and the discursive functions of comments, following established methodologies in digital media studies and environmental communication research (Braun and Clarke, 2021). It is noteworthy that these platforms exhibit different demographic profiles: YouTube is used across all age groups, Facebook has a broad but somewhat older audience, while TikTok's user base is significantly younger (Hootsuite, 2025; Pew Research Center, 2025). The comments on YouTube were ambivalent, expressing both admiration for innovative urban sustainability initiatives and anxiety about the erosion of natural ecosystems and potential technological “greenwashing,” with comments centering on four key topics: (i) comparisons between the functions and performance of Liquid3 and trees; (ii) urbanization and spatial constraints; (iii) technological innovations as the “lifesaver” of polluted megacities; and (iv) the symbolism and cultural meaning of trees. These



**FIGURE 2** Transformative potential of Liquid3. **(A)** Liquid3 in media and on the internet. **(B)** Map shows the number of companies from different countries that showed commercial interest in Liquid3. **(C)** Map shows the number of students, student groups or organizations that showed interest in Liquid3 in 50 different countries between mid-2022 and the end of 2025. The largest number of contacts came from India - 51. **(D)** Photos of educational activities facilitated by Liquid3. Sources: Campus Valinhos, Brazil; Dr Milena Dimitrijević; Shanghai Green Light-Year Environmental Service Center, China (top row, left to right); TTG LLC, Qatar; Greencajt Festival, Croatia (bottom row, left to right). Reproduced with permission.

views reflect a tension between eco-modernist optimism and ecological grief—people appreciate innovation but are wary of the symbolic replacement of nature with infrastructure. Similar key topics appeared in Facebook comments, but while YouTube

discussions emphasize narrative, symbolism, and existential concerns about civilization as a whole, Facebook users tend to shape environmental discourse through information exchange and contextual critique, focusing on operational considerations,

as well as urban policies and the context of specific cities, such as Manila or Delhi. Overall, public responses to Liquid3 on Facebook appear to articulate a worldview that is neither anti-technology nor naively eco-modernist, but one that seeks a coexistence of technological solutions with living ecosystems. On the other hand, TikTok users showed a near absence of ecological anxiety and rational evaluation of the technology. They perceived Liquid3 as an intriguing urban eco-gadget and a memetic object, rather than an environmental or policy instrument. Users engaged through humor, pop-culture references, and bio-ontological imagination (for example, hypothetical scenarios about what happens if a human or a tree becomes “merged” with Liquid3). Commenters do not express fear of replacing nature, nor do they mobilize grief, skepticism, or moral condemnation as on the other two platforms. Instead, TikTok frames Liquid3 as a site of hybridization between nature and technology, where conflict is replaced by absurdity and generative creativity, serving as material for cultural recombination and aesthetic experimentation. In conclusion, the analysis highlights that transformative design depends on an innovation’s ability to resonate within hybrid cultural frameworks, which in turn shape public acceptance. It is important to note that the analysis was limited to a single content creator, therefore a more comprehensive understanding of the social relevance of Liquid3 warrants further in-depth analysis.

The analysis indicates that Liquid3 induces a transformation in the social perception of alternative greening concepts and bio-inspired techno-environmental innovations, making these issues more widely known, more understandable, and a matter of public consideration. The term “liquid tree” has been introduced into popular culture, as well as into broader social and biotechnological discourse, paving the way for similar concepts. Communication and public discussion surrounding Liquid3 have also highlighted the value of trees and nature in urban contexts. Liquid3 demonstrates how innovative urban design can catalyze responsiveness and social engagement, which are essential for transforming mindsets toward more sustainable societies.

## 4 Educational potential

In common educational contexts, learning about climate change or urban air pollution mainly focuses on understanding the problem, i.e., explaining the greenhouse effect, sources of pollution, and monitoring methods, as well as discussing the potential consequences of rising temperatures and changing precipitation patterns or impacts on health and quality of life (Stevenson et al., 2017; Monroe et al., 2019). Rather than presenting concrete examples of active engagement, this approach has been criticized for relying primarily on fear-based messages, which can contribute to denial, emotional numbing, and apathy (Stoknes, 2015). Within this context, Liquid3 provides a tangible response to urban air pollution and the effective “deforestation” of cities. Through the materialization of processes that make environmental phenomena visible and intelligible, Liquid3 engages the public and demonstrates the educational potential of transformative design (Gabrys, 2016). Public-engaging interventions support

experiential, situated, and affective learning, offering meaningful educational opportunities (Wals, 2007). This aligns with long-standing arguments in environmental education that sustainability transitions require shifts not only in knowledge, but also in values, competencies, and imaginaries (Jensen and Schnack, 1997; Sterling, 2001).

From mid-2022 to the end of 2025, over 250 university and high-school students, student groups, and organizations from 50 countries proactively expressed strong interest in learning about Liquid3, reaching out to the inventors (Figures 2C, D). They showed interest in the technology and its applications, gathered materials for theses, student papers, promotional work, or the development of similar solutions, and looked for opportunities to introduce the technology to local policymakers. Such worldwide interest, also reflected on social networks in public media, underlines that Liquid3, as a solution to problems shared by different societies, may have significant multicultural transformative potential. Transformative initiatives that operate across cultural contexts enable the co-production of meaning, values, and practices among diverse publics, thereby expanding collective imaginaries of social and ecological futures (Wals, 2007). When design-led or educational interventions circulate through multiple cultural and linguistic environments, they facilitate plural forms of learning and engagement, allowing sustainability and innovation to be interpreted, contested, and re-embedded in locally specific yet globally connected ways (Gabrys, 2016). The Liquid3 concept appears to show potential as an educational interface, not only for environmental sciences and design but also for economics and business students, who have demonstrated interest in the innovation and increasingly engage with issues of sustainability transitions, green innovation, and mission-oriented economic change. Lectures explaining the Liquid3 concept, as well as the “Innovation Know-How Workshop” that uses Liquid3 to dissect the innovation process (Stojiljković and Spasojević, 2025), have been delivered to different groups and at various events, including FEBS Jr Section, Environmental Student Council of the Technical University of Munich, Instituto Superior Técnico—Universidade de Lisboa, University of Belgrade—Faculty of Architecture, EXPO Dubai 2020, GreenCajt Fest 2023 Zagreb, ConTeqExpo24 Doha, FEEL 2025 Program at Dubai Future Foundation, and Weekends Y-Team 2025 Belgrade. According to available data on social networks, over 20 student teams have been inspired by Liquid3 to develop microalgae-based air purifiers and have presented them at schools or public events. This highlights the need to incorporate the conceptualization, development, and evaluation of innovative transformative solutions into traditional curricula, providing educators with the means to inspire new ways of thinking.

## 5 Conclusions

Liquid3 extends beyond microalgae-based air purification, fulfilling the role of transformative urban design that can reshape how citizens imagine the relationship between nature, technology, and the future of cities. The core of Liquid3’s transformative potential lies in the materialization of discrete

ecological functions like oxygen production and carbon capture into visible forms in urban space. In doing so, Liquid3 may alter how environmental work is perceived and valued in public space. By occupying the same social and symbolic domains typically associated with trees—public squares, benches, shade, and rest—Liquid3 triggers processes of collective negotiation. Public reactions show that citizens attribute to trees not only biological functions but also emotional, cultural, and moral significance. Transformative design emerges through contrast and displacement: by simulating a single function of a tree, Liquid3 compels society to recognize the many other functions that trees perform. This reflexive effect is itself transformative, broadening civic awareness of ecological functions. At the same time, Liquid3 transforms how society perceives the role of technology in addressing ecological crises. Across social media, Liquid3 evokes different responses on different platforms, which calls for further, more detailed comparative analysis. In terms of educational potential, Liquid3 may serve both as a model of commercially viable techno-environmental innovation and as an inspiring educational tool. This case study illustrates how transformative design may operate across different cultural circuits and educational systems. By externalizing environmental processes into infrastructural devices rather than biological organisms, Liquid3 opens new possibilities for design-led sustainability, making climate adaptation visible, debatable, and potentially co-owned by urban publics. Liquid3 is not a replacement for trees, but a piece of transformative urban design that provokes environmental imagination and civic engagement—while highlighting the vulnerability of urban environments.

## Author contributions

DS: Resources, Writing – original draft, Conceptualization, Writing – review & editing. IS: Writing – review & editing, Resources, Visualization.

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