Scoring the invisible:
Biomaterial and computational processes for [re] capturing atmospheric pollution

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Abstract

This article discusses the computational and material interplays embedded in the making of *[re]capture*, a research–creation project combining a bio-inspired installation that materialises particulate matter, together with outdoor sensing instruments that collect atmospheric data in at-risk neighbourhoods (Montreal, Canada). With impacts on health and the environment, habitual and slow forms of exposure to atmospheric pollution (Hsu 2016) outline the relationality of air and the porosity of bodies, both human and more-than-human (Nieuwenhuis 2016; Albano 2022). *What kind of technical objects, and material-esthetics can "negotiate a rapprochement" (Gissen 2009, 22) with the invisible materiality of air?* At the intersection of critical and bio-design, mechanical engineering, and computer science, *[re]capture* delves into this question through the lens of 'filtration,' simultaneously envisioned as a physical process for attending to atmospheric pollution, and as a generative concept for interpolating technology, materiality, and the city. While the artwork iterates a virtual testing model (Blender and *ossia score*) with physical prototyping, the article examines how to compose with air through digital simulation and scoring to create new alliances between porous meshes, bioindicators, data, particulate matter, light, wind, and electronics. It also asks *How to design installations that embody and materialise the affective properties of air?* Attending the speculative trajectory of this process, the article draws on feedback from computer-aided simulation techniques and collaborative experiments in residency spaces to investigate the 'scoring' of [im]materiality and explore the spatio-temporality of air.

Introduction

On June 25, 2023, 116 active forest fires ravaged northern parts of Quebec (Canada). A cloud of heavy smog blanketed the city of Montreal, which unusually recorded the worst air quality in the world (Bordeleau 2023; IQAir 2023). Local journal *La Presse* described the surreal aspect of the city's atmosphere: "one of Montreal's largest parks is deserted. In the background, [...] the Olympic Stadium towers into greyness. Its roof sparkles with orange reflections. The *Montérégiennes*, the mountains you usually see on the horizon, have disappeared"[1] (Dussault 2023). In *Subnature*, Gissen discusses how aerial substances like smoke, dust, and gases are "envisioned as threatening [...] to the material formations and ideas that constitute architecture" (2009, 22). Contrasting with more "desirable forms of nature—e.g., the sun, clouds, trees, and wind" (*ibid.*), this brief smog episode mobilised

1 Translated from French. Original reads: "l'un des plus grands parcs de Montréal est déserté. En arrière-plan, la tour du Stade olympique s'incline dans la grisaille. Son toit scintille de reflets orangés. Les Montérégiennes, ces montagnes qu'on voit habituellement à l'horizon, ont disparu."

public debate around climate change by drastically destabilising our sensory perception of the built environment. However, slower, more subtle, and habitual forms of exposure to "bad air," "present everywhere, but in barely noticeable quantities," (Hsu 2016, 797) also command attention. For example, particulate matter generated by transport and construction activities also has critical impacts on human health, temperatures, and vegetation (Health Canada 2016; Manisalidis et al. 2020; Ville de Montréal 2022; Government of Canada 2022).

"Planetary exploitation practices affect the substrates. Water, air, land" and "modify biological capacities" (Clément 2022, 16). Embedding both "matter and movement" (Albano 2022, 2), breathing or photosynthesis point to the human and more-than-human "porosity and sensitivity to the surrounding environment" (*ibid.*, 4), and emphasise how air combines "in an indissociable way being-there and being-with" (*ibid.,* 11). The relationality of air (Nieuwenhuis 2016) thus asks pressing questions pertaining to the politics, technologies, and practices involved in the design of built environments (Chen 2011; Graham 2015; Calvillo 2018; Liboiron and Lepawsky 2022). What kind of interventions, technical objects, and material-esthetics can "negotiate a rapprochement" (Gissen 2009, 22) with "the complex histories" (Schuppli 2020, 18) of air, a milieu that is felt although invisible?

Designers, artists, and architects tackled this question through a wide range of practices. Contemporary to the speculative domes of R. Buckminster Fuller and Shoji Sadao (1960), ORPROJECT (2015) proposed lightweight enclosed structures isolating humans from toxic climates. R&Sie(n) (2002) imagined building envelopes attracting particulate matter, and Graviky Labs (2017) transformed that particulate matter into ink. In contemporary art, HeHe (2008), Janine Randerson (2012, 2018), and Amy Balkin (2004–Ongoing) have visualised emanations through images and data processing. Michael Pinski (2017), Pablo Reinoso (1998), and Rafael Lozanno-Hemmer's (2013) inflatables emphasise the shared haptic and olfactive dimensions of air, and Tomás Saraceno's (2022) floating installations propose a reflection on energy futures and interspecies collaboration. Finally, at the intersection of art and science, the participatory approaches of Beatriz da Costa (2012), Jennifer Gabrys (2013), Alexandre Castonguay (2015), and others engage citizens in the design of accessible instruments for gathering air quality data.

At the intersection of critical and bio-design, mechanical engineering, and computer science, *[re]capture* scaffolds on this established body of practices and materialises air toxicity through the lens of 'filtration.' Designed by researchers and students at Concordia University, and intended for artistic audiences and citizens interested in issues of air quality, the artwork couples a bio-inspired indoor installation with a series of outdoor sensing instruments that capture atmospheric data in at-risk neighbourhoods (Montreal, Canada). Beyond a subtractive technique for air purification, filtration is envisioned as an interplay between computational and material processes. Computer-aided design software (Blender), a scoring platform (*ossia score*), and physical prototyping iterate to interface semi-living porous meshes and living bioindicators together with data, particulate matter, light, wind, and electronics. While to "recapture" means "to re-experience" a situation (Collins 2023), this generative process interpolates technology, materiality, and the city to dynamically experiment with the heterogenous relations between the form and behaviours of air (Brayer and Migayrou 2013; Yiannoudes 2023). Cardoso-Llach (2015) writes that software "play[s] a crucial role in regimenting and organizing the aspirations and everyday practices of designers [...] as well as the shape of the built environment" (151). Based on collaborative team workshops, this article explores its use in the context of trans-disciplinary questionings surrounding the authoring of the piece: *How to compose with an intangible medium like air? How can digital simulation and scoring create new alliances with electronics and biomaterials? How to design installations that embody and re-materialise some of its affective properties, such as particulate matter?* Attending the speculative trajectory of this process, the reflection draws on feedback from computer-aided simulation techniques and collaborative experiments in residency spaces to specifically investigate the 'scoring' of [im]materiality and explore the spatio-temporality of air.

Materials and methods

[re]capture2 (Fig. 1) is integral to a broader research project on membranes (*Membranes souples dynamiques*, 2020–2024) and embraces research–creation as a core approach. Combining academic research and creative practice (Léchot Hirt 2015; Springgay and Truman 2018), research–creation intersects the material–speculative territory of art and design with perspectives in humanities, science, and social sciences to propose objects, interventions, and events that stimulate "ethical, artistic, political, technological and environmental reflection" (Jarry et al. 2022). By "making the results and outcomes of the creation usable" (Bianchini 2015) outside of the artistic or research process, research–creation articulates esthetic, methodological, and theoretical knowledge around critical matters of societal concern.

2 https://vimeo.com/manage/videos/743974327

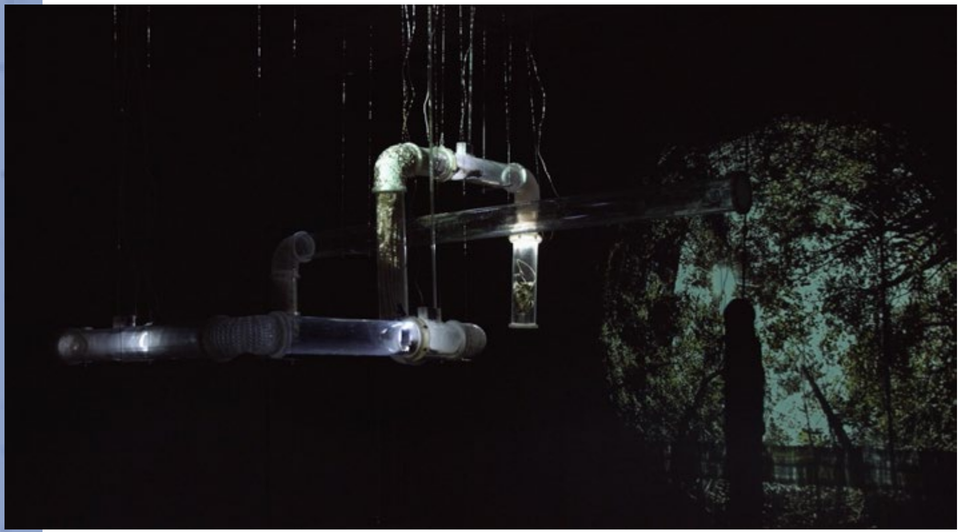

Figure 1 *[re]capture* prototype at artist-run centre Perte-de-Signal. Montreal, 2022.

[re]capture is being developed by a team of six researchers and student-researchers associated with the Milieux Institute for Arts, Culture, and Technology at Concordia University (Montreal). Two platforms support the research: The Concordia University Research Chair in Critical Practices in Materiality[3] and its affiliated laboratory, the Milieux Speculative Life Biolab.[4] At the intersection of cultural, scientific, and citizen initiatives, the Chair combines research–creation with practices in material and environmental sciences to investigate how residual, bio-inspired, and active materials can generate novel aesthetic, critical, and political responses to the intricate interactions between technology, humans, and ecosystems. Sustaining this research on socio-environmental issues surrounding material production, the Speculative Life Biolab is an interdisciplinary laboratory dedicated to examining the Technosphere, and how it impacts the changing status of life on the planet. Under the development towards a final exhibition dedicated to the arts community but also to general publics mobilised by environmental issues (2024, curator: Ariane Plante), the work discussed in this article was prototyped and experimented with at Perte-de-Signal (Summer 2022) and at the Milieux Institute during three team workshops with students and researchers. The workshops involved the physical installation and a virtual testing model composed of its Blender counterpart and the software *ossia score* (2022–2023).

3 https://materials-materiality.ca/

4 https://speculativelifebiolab.com/

Material methods

[re]capture is a flexible system of interchangeable tubes floating above ground. Sporadically illuminated by LED lights (Fig. 2), this environment filters dust and particulate matter thanks to living ecosystems and porous bio-inspired scaffolds: custom 3D abacá foam structures (Fig. 3), bioplastic surfaces (Fig. 4), moss (Fig. 4), and strawberry plants (Fig. 5). While the piece accommodates different configurations (Bogue 2007), its physical behaviours are informed in real-time by two sets of DIY (do it yourself) outdoor sensing instruments: Six Nomad Air Kits that measure air quality,

and one Air Turbine that transforms wind energy into electrical signals. Sending real-time data to an online database, these instruments trigger tangible material accumulations, variable air flows, and shifting light patterns in the installation. Placed in neighbourhoods bordering road infrastructures, each Nomad Air Kit (Fig. 6) supplies the gallery installation with data such as levels of particulate matter (PM 10, PM 2.5), volatile organic compounds (VOCs), CO_2, and temperature. The solar-powered kit also transmits its GPS coordinates and records its environment using a 360-degree camera. The Air Turbine (Fig. 7) is a vertical axis instrument whose double blades include a 3D-printed mesh filled with expanded abacá fibres, a species of plant indigenous to the Philippines with a great structural versatility, also used in papermaking. While particulate matter slowly accumulates in this outdoor filter, wind speed is communicated to the installation.

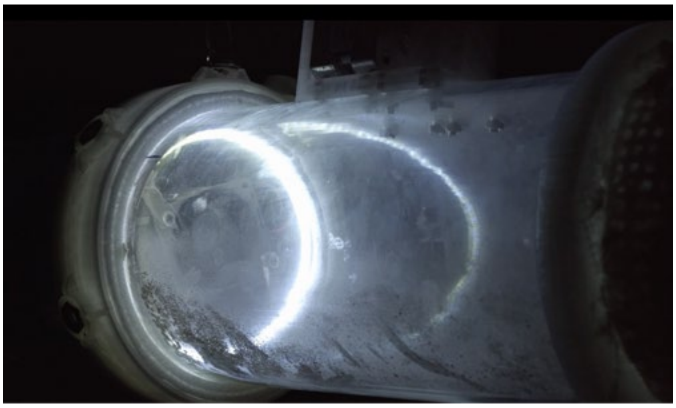

Figure 2. LEDs illuminating dust and particulate matter.

Figure 3. Abacá filtering structure.

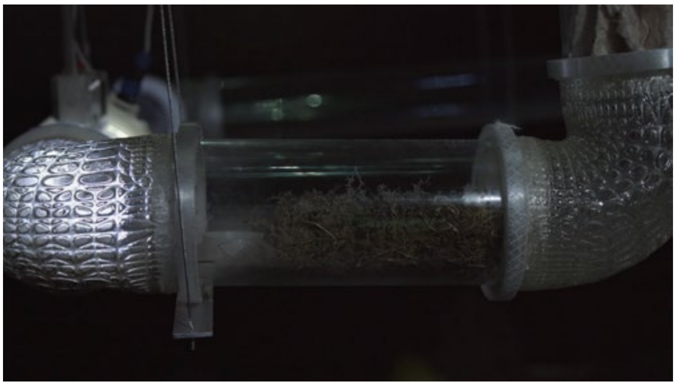

Figure 4. Bioplastic surface and moss module.

Figure 5 Strawberry plant module.

Figure 6 Nomad Air Kits capturing air quality data.

Figure 7 Air Turbine gathering wind speed data and particulate matter.

Software methods

A core critical question is how to make air and its related processes tangible. If it is impossible to be "outside of air," it is also difficult to circumscribe this milieu within precise limits (Hauser 2016). *[re]capture's* filters and bioindicators operate at the interface of environment and atmospheric pollution and aim at revealing—through their saturation—the socio-political, technological, and material residue of urban atmospheres (Douglas 1966; Gandy 2017). So, *How can computer software support this process?*

[re]capture's data processing design follows a model-based approach involving the creation of an interactive 3D model of the piece, iterated over along with the real-world artistic installation. Beyond a static 3D object or a preparatory mock-up, it reacts to the same stimuli as the physical installation and allows the study of the system's holistic properties. Defined as an "organizing outlook upon the real" by Longo and Zakhama (2013), the model is both methodological and goal-oriented: "In this role of mediation in relationship to knowing subject and object of empirical study, the substituent/substitute is a basic link in the method capable of answering to the challenge of engineering" (160).

To find the right scale and properties for this computerised model, a balance is to be struck between the requirements of the artists, developers, engineers, students, available resources in a university environment, and the physical necessities of the project. In addition, to explore the possibility of composition, change, and transformation of air over time, the software iterations have to follow the physical Design for Disassembly—or reassembly—principles of the piece (Bogue 2007). This process demands an interplay between data and materiality: Informed by real-time sensing metrics, elements of the artwork such as the LEDs, the motors, and the fans that propel the air alter their state, resulting in observable—yet arcane—changes to the data physicalisation occurring in the artwork. The rules embedded in this interplay are defined through *ossia score* (Celerier 2015), a visual programming language (Edwards 1988) that combines data flow and non-linear temporal evolutions—or interactive scores—in a single graphical user interface (GUI). *ossia score* is a software implementation of the *interactive score* ontology (Desainte-Catherine 2005), to be understood as a written set of steps that can react and adapt to changes occurring in the real world. Interactive scores are expressed in a way amenable to artistic creation and exploration for non-computer programmers, a challenge addressed through visual diagrams encoded in the *ossia* domain-specific visual language.

This technology involves intricate mappings and temporal structuring of air to render *[re]capture*'s evolving behaviours visually obvious to the score author, whether they concern short-scale fan and motor activation, or longer progressive parameter mappings.

Flow is controlled and directed by environmental data through a set of simple rules evolving over time and encoded in *ossia*. Such rules could be, if translated into English, "whenever CO_2 reaches a specified limit, trigger a dust/particle drop in the circuit and blink the lights at high frequency. After a one-minute hysteresis, if the CO_2 values have reached safer levels, revert to normal operation." This process implies logical constraints, a real-time dimension, live data input, and control of electronic boards—Raspberry Pi and Arduino microcontrollers—which activate the motors and the lights to visualise the changes in atmospheric data.

Discussion and analysis: Developing physical instruments and virtual models

Per Marder (2016), dust "is an excess of time over space" (43). Contrasting the geological, fossil, industrial, human, or plant durations embedded in this materiality with the small space it occupies in its expanded environment—the air—this idea of "excess" also echoes Parikka, who underscores the "immodest countlessness" (2014 88) of dust. Always plural, dust—and by extension particulate matter—forms with air invisible collectivities that operate below the threshold of human perception, forcing "us to rethink boundaries of individuality as well as space" (*ibid*.). [*re]capture's* enclosed modules are porous meshes, foams, scaffolds, and living matter precisely designed to accelerate and concentrate this "excess of time" and "immodest countlessness" at their surface.

Interfacing with the temporality of air, each installation module—or tubular section—emerges from an "iterative relationship between research and creation" (Bianchini 2015) based on a set of reusable techniques, development methodologies, software, hardware, and materials. However, some of *[re]capture*'s processes or material "instruments" (*ibid.)* also grow and evolve at their own rhythm. Abacá fibre is foamed and dried into 3D filters following traditional paper-making techniques. Moss (bryophytes) and strawberry plants (fragaria) record the complex interactions between urban air and particulate matter through their boundary layer (Kimmerer 2003) and their sticky trichomes. Finally, bioplastic surfaces made of gelatin, water, and glycerol gain their filtering stickiness thanks to a slow cooking and additive dipping process. This engagement with the living and the semi-living is filled with uncertainties and requires observation, time, and maintenance (Puig de la Bellacasa 2017). For example, abacá fibres will compress and stop filtering if not dried properly, mosses will turn yellow if exposed to improperly filtered air, and strawberries' growth will be impacted by a restrained environment.

Working with material transformation, as well as with environmental and technological conditions, demands a parallel iterative development process, a technology that is "neither a tool of representation or figuration, but rather a 'proto-prototype' [...] building bridges between [...] generative processes" (Brayer 2013, 18). This process aims at the creation of a modular, reusable, and replicable system that would make experimentation easy, without having to work at all times with the actual materials of the piece. As Weinstock (2006) outlines, "testing, modifying the material and producing new samples is usually a long series of repetitive physical experiments [...] that continues until a suitable compromise between manufacturing constraints and acceptable performance is reached, and full-scale production can begin" (59). While "the writing of algorithmic protocols must be articulated with nature's resistance" (Brayer 2013, 19), *[re]capture*'s virtual testing model "replaces most, but not all, physical testing, which can be reserved for the final prototypes" (Weinstock 2006, 59). The proposed iteration loop for the electronic and software design follows this general pattern: a model is created and used for behaviour simulation with Blender and ***ossia***, and re-iteration occurs across the piece's assembly stages (Fig. 8).

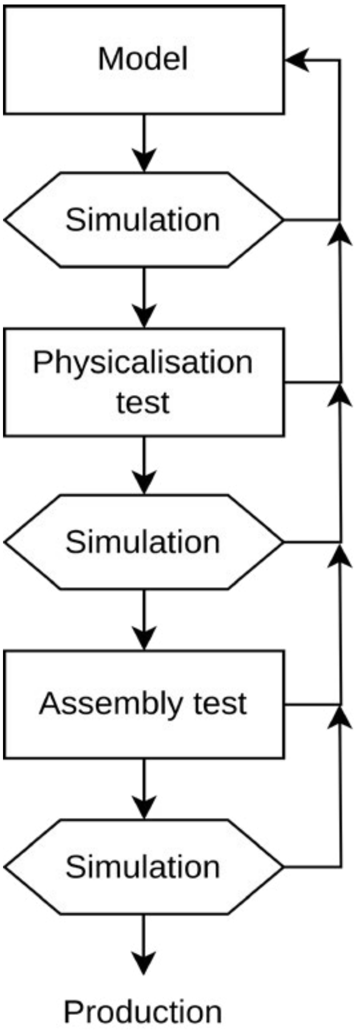

Figure 8. Proposed iteration and feedback loop for the development of the installation.

[re]capture's feedback loop could align with Susan Stepney's notion of cyber-bio-physical systems—"a tight feedback loop of increasingly sophisticated artefacts, requiring and grounding increasingly sophisticated scientific advances, enabling further progress in the engineering domain" (2023). [re]capture can be seen as such a system: as a metaphorical microcosm for the physicalisation of atmospheric data, it leverages the cyber-, bio-, and physical-aforementioned elements, and combines them harmoniously through a modular and re-adaptable design.

In this simulation methodology, Blender provides a remotely-controllable real-time visual render of the artwork, while *ossia* score manages the interactions, temporal semantics, and dataflow of the incoming sensors, with the same 'score' being used for both the Blender simulation and the actual installation. This strategy was documented in the official *ossia* user-guide. [5]

Ossia is used to score the LEDs, motors, and fan patterns, at once to visualise the behaviours occurring in Blender, and to actually trigger said

5 https://ossia.io/score-docs/integrations/blender.html

behaviours when connected to the physical installation. This aims at ensuring that the physical installation is as close as possible to what is observed during the simulation. Figure 9 outlines the general architecture of this system.

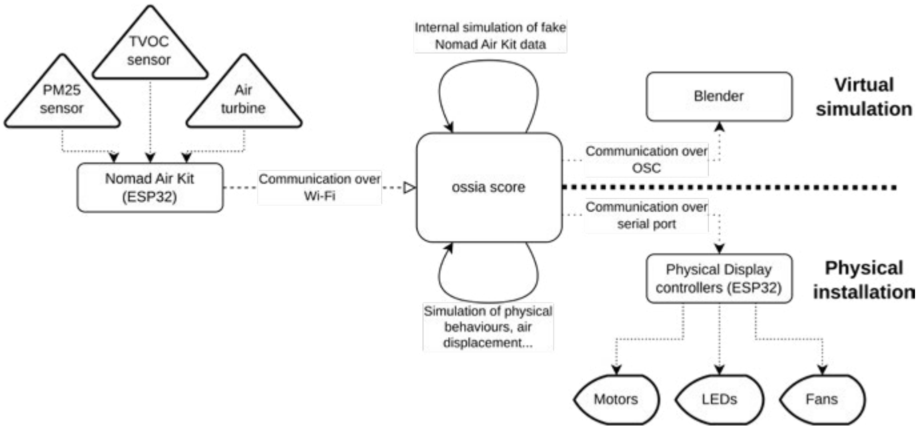

Figure 9 Organization of *[re]capture*'s software system.

Envisioned as a material, social, and environmental arrangement (Cardoso Llach 2015), *[re]capture*'s virtual testing 3D model embodied the ideas of the team in as much as the potential of its more-than-human collaborators. A question central to this process is the definition of meaningful interactions between the spatiality and temporality of matter—moving, chaotic, and unpredictable—and the agency of the researchers who aim to write in a symbolic language with strong temporal semantics to direct such behaviours. This interplay must also result in visible and somewhat understandable outcomes for the audiences who experiment with the work. The software system at the centre of this trichotomy uses multiple metaphors and devices to engage the conundrum. The temporality of the air is made manifest thanks to the timely triggering of LEDs, emphasising dust and particle movements inside the tubes. On the simulation side, the activation of motors and fans is visualised with cubes denoting their current activity (Fig. 10).

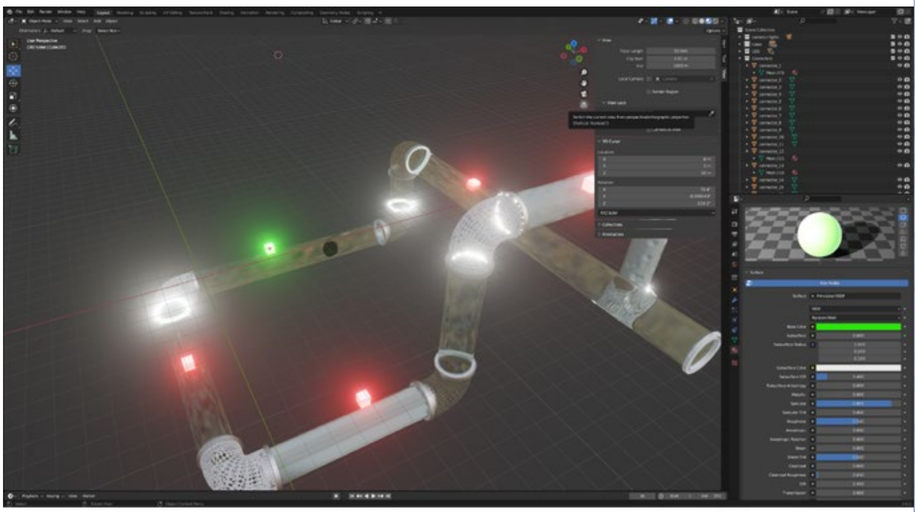

Figure 10. Interactive model of *[re]capture*'s structure in Blender. LEDs—bright circles—and motors—red and green cubes—receive a live data feed from *ossia score*.

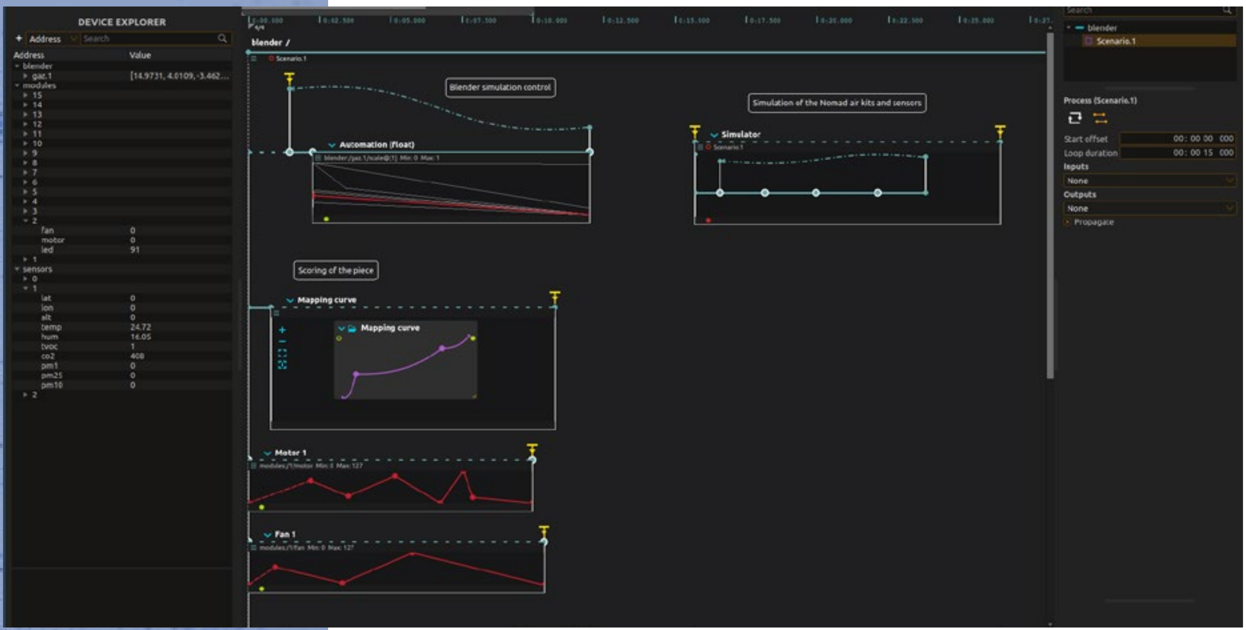

Figure 11 Template score containing all the elements of *[re]capture* in a simplified form.

The data processing occurring in *ossia score* is not a simple linear mapping from inputs (e.g., air quality data and wind speed provided by the Nomad Air Kits and the Air Turbine) to outputs (motors, fans, LEDs) but rather a rich description of temporal evolution, which can occur at multiple time scales. On short time scales, temporal scores define how the LEDs and motors react to the fans and embody the short-time temporalities of air being blown out. On longer time scales, variations on mappings from input data to the electronics take place: for ten minutes, the activation of a specific motor may be tied to the temperature monitored by the Nomad Air Kits, and for the ten next minutes, a different mapping leverages the Air Turbine's flow to drive behaviours in the installation. Figure 12 illustrates the way *[re]capture* sits at the crossroads of these diverse scales while proposing a cohesive system.

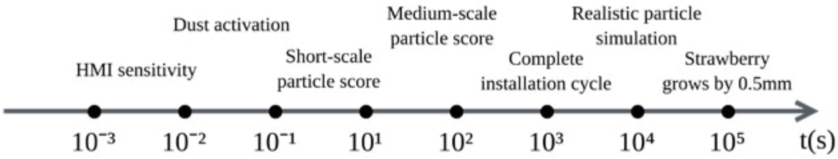

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Figure 13 Workshop showing the combined use of Blender and *ossia.*

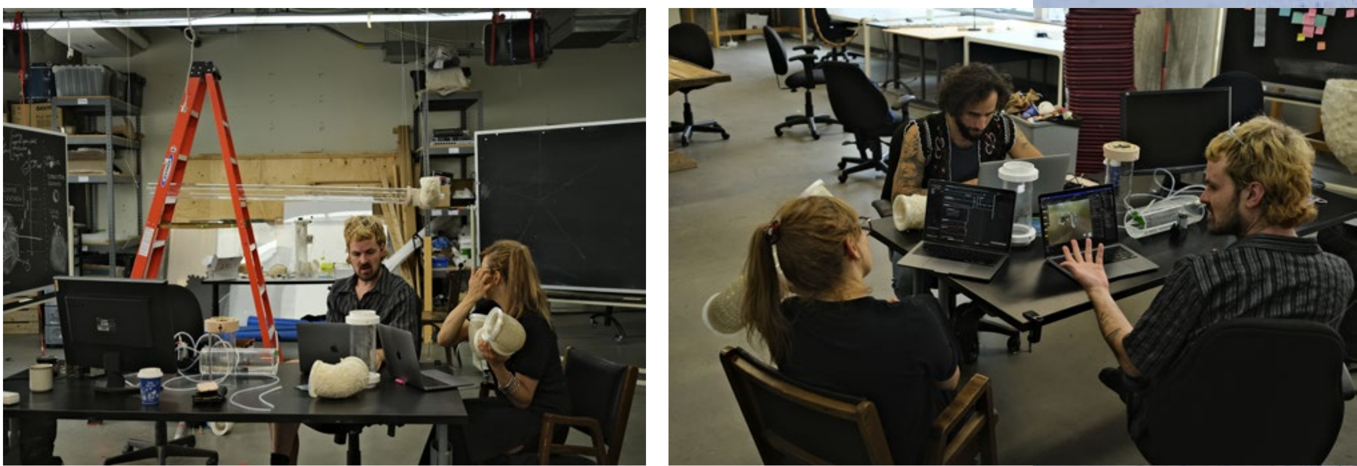

Figure 14 . Work session for the integration of a new water-pump-based module in the piece.

This 'porous' approach allowed for crucial observations and potential ways forward to emerge. Among the research team developing the work, long-term engagement with materiality led to an embodied understanding of the physical responses of the installation. In addition to the spatial scale of work that involves the researchers' and students' bodies moving in and around the artwork, senses of sight, hearing, and touch played a key role in the way the team anticipated *[re]capture*'s present and future fragilities and potentials. In material terms, the nonlinearity of dust and particulate matter's movement could not be fully anticipated. The 3D Blender model and the *ossia score* platform are precious tools for controlling fan activation, light, and air flow durations. However, neither can model the force and behaviour of air in relation to other elements, such as the variable and shifting length of the tubes or the porosity and transformation of abacá, strawberry, and moss filters over time. Reminding the researchers and students how particulate matter and dust are simultaneously "spatialized time and temporalized space" (Marder 2016, 46), discovering the distributed agency of the material and computational elements remains a heuristic process. Fostering sensitivity to, and affectivity with, unexpected material events deemed environmentally undesirable (e.g., a pile of dust beautifully forming in a particularly well-lit area of the installation, as shown in Fig. 15), the process also enhanced such events through physical adjustments to the configuration of the installation.

Figure 15. Unexpectedly, dust, particulate matter, and light create intricate configurations.

Significantly, the affordances and behaviours between human and software, as well as between software themselves, are fundamentally distinct in the simulation and on the installation: communication protocols, user interface clarity, and abstractions for parametric design were questions which stemmed from the workshop sessions. The physicalisation of air properties, which is partly done through blowing dust and particulate matter in the tubes of the installation, can only be reproduced schematically due to material and temporal constraints. Indeed, the users (researchers and students) of the simulation system do not have access to computers which would enable precise and realistic real-time simulation of microscopic particles at the scale of the installation. Such simulations could take hours, while the temporalities of making require real-time results to enable a quick feedback and iteration loop.

By considering *[re]capture* as an evolving system or organism rather than a fixed object, these workshops underlined the need for recursive modulations between the hypothesis phase, the scoring, the modelling, and the physical activation of the artwork. Researchers and students' feedback and a study of the ergonomy issues encountered while trying to design specific behaviours drove the authoring software *(ossia)* enabling the virtual 3D testing model (Blender) towards new in-progress directions. Notably, ongoing developments focus on simplifying and automating the creation of the link between the simulation in Blender and *ossia score*, as well as enabling more general parametrisation of the system and better visualisation of the score's execution.

Findings and conclusions

[re]capture relies at once on bio-design, materials, physics, and software engineering to activate atmospheric data (particulate matter, volatile organic compounds, CO_2, and temperature) and foster the accumulation of particulate matter and dust in a modular tubing system, thus rendering tangible invisible air properties. This is achieved at multiple scales through the scoring of materiality filtered inside the in-progress installation. Over time, atmospheric pollution greys out the porous abacá fibre meshes, covers bioplastic scaffolds, surrounds the microstructures of moss and strawberry plants, and creates intricate light patterns. How could software support this trajectory from air properties to digitised data, and finally toward complex distributed material behaviours? The challenge being not only to 'demonstrate' the circulation of air and its materiality, but to enhance its agency and activate new imaginaries and forms of affectivity with this invisible milieu. Demanding "digital technologies for design with social, material, and spatial dimensions" (Cardoso Llach 2015, 4), this question yielded a year-long feedback and iteration loop on the scoring of the piece. Both "sensitive and critical toward the socio-technical frameworks deployed" for *[re]capture*'s production (*ibid.*, 151), this iterative process considered collaborative work across a large team, embodied material knowledge of the researchers and students, material serendipities and contingencies, and a university environment with intermittent access to the physical installation. For this, the team leveraged a model-based methodology that enables simulation—via a virtual 3D testing model based on Blender and *ossia score*—of some of the physical, spatial, and temporal properties and behaviours expected for the installation (e.g., wind, light, and particle distribution). Yet, while parametric design allows for integrating complex environmental or social variables (Madkour 2009), developing relevant interplays between air, data, and the physical properties of the installation could not be sustained through mere engineering. Based on the real-time data feeds of the Nomad Air Kits and the Air Turbine—custom air quality sensors distributed in the city of Montreal (Canada)—the research–creation process involved the design and testing of several protocols for collaboration; engagement with, and documentation of, the transformation of living and semi-living materials; and the iterative design of electronics. As it stands, this model-based

approach for simulation favours reciprocity over autonomy and is still being iterated upon along with the piece toward the final version of the installation that will be exhibited in 2024. Although this process currently has limits, in particular for the delicate real-time simulation of air and particle flow, it demonstrates potential for addressing different temporalities beyond the inclusion of the real-time data feed or live control of electronics. As such, taking into account the scoring of biological elements and longer-term ecological agencies, *[re]capture* alludes to the next step.

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R E F E R E N C E S

Albano, Catarina. 2022. *Out of Breath: Vulnerability of Air in Contemporary Art*. Minneapolis: University of Minnesota Press.

Bianchini, Samuel. 2015. 'Towards Organogenesis: For an Instrumental Approach in Research in Art.' *Journal of the New Media Caucus* 11 (3). http://median.newmediacaucus.org/research-creation-explorations/towards-organogenesis-for-an-instrumental-approach-in-research-in-art/

Bogue, Robert. 2007. 'Design for disassembly: A critical twenty-first century discipline.' *Assembly Automation* 27 (2): 285–289.

Bordeleau, Jean–Louis. 2023. 'Tout le sud du Québec enfumé par les feux du Nord.' *Le Devoir*, June 25, 2023. https://www.ledevoir.com/societe/793552/tout-le-sud-du-quebec-enfume-par-les-feux-du-nord

Brayer, Marie-Ange, and Frédéric Migayrou. 2013. *Naturalizing Architecture*. Orléans: HYX.

Brayer, Marie–Ange. 2013. 'Nature and Artifice: Affects and artefacts in naturalized architecture.' In *Naturaliser l'architecture,* edited by Marie–Ange Brayer, and Frédéric Migayrou, 14–37. Orléans: HYX.

Calvillo, Nerea. 2018. 'Political airs: From monitoring to attuned sensing air pollution.' *Social Studies of Science* 48 (3): 372–388.

Cardoso Llach, Daniel. 2015. *Builders of the vision: Software and the Imagination of Design*. London: Routledge.

Celerier, Jean-Michaël, Pia Baltazar, Clément Bossut, Nicolas Vuaille, Jean-Michel Couturier, and Myriam Desainte-Catherine. 2015. 'OSSIA: Towards a unified interface for scoring time and interaction.' In *Proceedings of the First International Conference on Technologies for Music Notation and Representation*. Paris.

Chen, M. Y. 2011. 'Toxic animacies, inanimate affections.' *GLQ: A Journal of Lesbian and Gay Studies* 17 (2–3): 265–286.

Clément, Gilles. 2004. *Manifesto of the third landscape*. Lund: Trans Europe Halles.

Collins Dictionary. 'Recapture.' Accessed July 1, 2023. https://www.collinsdictionary.com/dictionary/english/recapture

Desainte-Catherine, Myriam, and Antoine Allombert. 2015. 'Interactive scores: A model for specifying temporal relations between interactive and static events.' *Journal of New Music Research* 34 (4): 361–374.

Douglas, Mary. 1966. *Purity and Danger: An Analysis of the Concept of Pollution and Taboo*. New York: Routledge.

Dussault, Lila. 2023. 'À Montréal les pires bouffées d'air.' *La presse*, June 25, 2023. https://www.lapresse.ca/actualites/grand-montreal/2023-06-25/a-montreal-les-pires-bouffees-d-air.php

Edwards, Alistair D. N. 1988. 'Visual Programming Languages: The Next Generation.' *SIGPLAN Not.* 23 (4): 43–50.

Gabrys, Jennifer. 2013. 'Ecological observatories: Fluctuating sites and sensing subjects.' In *Field_Notes: Field and Laboratory as Sites for Art & Science Practices,* edited by Laura Beloff, Erich Berger, and Terike Haapoja, 178–187. Helsinki: Finnish Society of Bioart.

Gandy, Matthew. 2017. 'Urban Atmospheres.' *Cultural Geographies* 24 (3): 353–374.

Gissen, David. 2009. *Subnature: Architecture's other's Environments.* New York: Princeton Architectural Press.

Government of Canada. 'Health impacts from air pollution.' Accessed May 1, 2022. https://www.canada.ca/en/environment-climate-change/campaigns/canadian-environment-week/clean-air-day/health-impacts-air-pollution.html

Graham, Stephen. 2015. 'Life support: The political ecology of urban air.' *City* 19 (2–3): 192–215.

Hauser, Jens. 2016. ''Atmosph-air? Atmos-faire.' In *Man Made Clouds*, edited by HeHe, 39–60. Paris: HYX.

Health Canada. 2016. 'Conseils pour l'évaluation des impacts sur la santé humaine dans le cadre des évaluations environnementales: qualité de l'air.' publications.gc.ca/pub?id=9.802344&sl=1

Hsu, Hsuan L. 2016. 'Naturalist Smellscape and Environmental Justice.' *American Literature* 88 (1): 787–814. Durham, NC: Duke University Press.

IQAir. 'Air Quality in Montreal.' Accessed June 25, 2023. https://www.iqair.com/us/canada/quebec/montreal

Jarry, Alice, Marie-Pier Boucher, Brice Ammar-Khodja, Brice, Lee Wilkins, Vanessa Mardirossian, and Samuel Bianchini. 2022. 'Form-Taking/Force-Shaping.' *Antennae: The Journal of Nature in Visual Culture* 59: 58–73.

Kimmerer, Robin Wall. 2003. *Gathering Moss: A Natural and Cultural History of Mosses*. Corvallis, OR: Oregon State University Press.

Léchot Hirt, Lysianne. 2015. 'Recherche-création en design à plein régime: un constat, un manifeste, un programme.' *Sciences du Design* 1 (1) : 37–44.

Liboiron, Max, and Lepawsky, Josh. 2022. *Discard Studies: Wasting, Systems, and Power*. Cambridge, MA: MIT Press.

Longo, Giuseppe, and Nabil Zakhama. 2013. 'Le modèle comme regard organisateur du reel.' In *Naturaliser l'architecture,* edited by Marie-Ange Brayer, and Frédéric Migayrou, 158–187. Orléans: HYX.

Madkour, Yehia, Oliver Neumann, and Halil Erhan. 2009. 'Programmatic Formation: Practical Applications of Parametric Design.' *International Journal of Architectural Computing* 7 (4): 587–603.

Manisalidis, Ioannis, Elisavet Stavropoulou, Agathangelos Agathangelos, and Eugenia Bezirtzoglou. 2020. 'Environmental and Health Impacts of Air Pollution: A Review.' *Frontiers in Public Health* 8 (14): 1–13.

Marder, Michael. 2016. *Dust.* New York: Bloomsbury.

Nieuwenhuis, Marijn. 2016. 'Breathing Materiality: Aerial Violence at a Time of Atmospheric Politics.' *Critical Studies on Terrorism* 9 (3): 499–521. https://doi.org/10.1080/17539153.2016.1199420

Parikka, Jussi. 2014. *A Geology of Media*. Minneapolis: University of Minnesota Press.

Puig de la Bellacasa, Maria. 2017. *Matters of Care: Speculative Ethics in More than Human Worlds*. Minneapolis: University of Minnesota Press.

Randerson, Janine. 2018. *Weather as medium: Toward a meteorological art.* Cambridge, MA: MIT Press.

Schuppli, Susan. 2020. *Material Witness: Media, Forensic, Evidence.* Cambridge, MA: MIT Press.

Service de l'environnement—Ville de Montréal. 2022. 'Bilan environnemental 2022: qualité de l'air à Montréal.' Accessed May 30, 2022. https://portail-m4s.s3.montreal.ca/pdf/bilan_qualite_air_2022_final_v2.pdf

Springgay, Stephanie, and Sarah E. Truman. 2018. *Walking methodologies in a more-than-human world: WalkingLab.* London: Routledge.

Stepney, Susan. 2023. 'Life as a Cyber-Bio-Physical System.' In *Genetic Programming Theory and Practice XIX. Genetic and Evolutionary Computation*, edited by Leonardo Trujillo, Stephan M. Winkler, Sara Silva, and Wolfgang Banzhaf, 167–200. Singapore: Springer.

Weinstock, Michael, and Nikolaos Stathopoulos. 2006. 'Advanced simulation in design.' *Archit Design* 76: 54–59.

Yiannoudes, Socrates. 2023. *Architecture in Digital Culture: Machines, Networks, and Computation*. New York: Routledge.

REFERENCED ARTWORKS

Balkin, Amy, *Public Smog*, 2004–Ongoing. https://www.publicsmog.org/

Buckminster Fuller, R., and Shoji Sadao, *Dome Over Manhattan*, 1960. https://artblart.com/tag/shoji-sadao-dome-over-manhattan/

Castonguay, Alexandre, *Cocíclo*, 2015. https://15.piksel.no/cociclo-alexandre-castonguay-thomas-ouellet-fredericks/

Da Costa, Beatriz, *Pigeon Blog*, 2006. https://nideffer.net/shaniweb/pigeonblog.php

Graviky Labs, *Air Ink*, 2017. https://air-ink.com/

HeHe, *Nuage Vert*, 2008. http://hehe.org.free.fr/hehe/NV08/index.html

Lozanno–Hemmer, Rafael, *Vicious Circular Breathing*, 2013. https://www.lozano-hemmer.com/vicious_circular_breathing.php

Pinski, Michael, *Pollution Pods*, 2017. http://www.michaelpinsky.com/wp-content/uploads/2017/08/263-9-PB.pdf

ORPROJECT, *Bubbles*, 2015. https://orproject.com/bubbles/

Randerson, Janine, *Neighbourhood Air*, 2012. https://ada.net.nz/artbase/neighbourhood-air/

Reinoso, Pablo, *La parole*, 1998. https://less-ismore.tumblr.com/post/85150125722/pablo-reinoso-la-parole-1998

R&Sie(n), *Dusty Relief*, 2002. https://www.new-territories.com/roche2002bis.htm

Saraceno, Tomás, *Oceans of Air*, 2022. https://studiotomassaraceno.org/oceans-of-air/