CYCLING

the system

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UPCYCLING the system

From dogmas to operational realism toward Regenerative Architecture

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“To dwell is not merely to occupy a space,
but to interweave our lives with the memory of
places and materials that welcome us”

(Juhani Pallasmaa, *Habitar*, 1994)


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RESPONSIBLE
CONSUMPTION
AND PRODUCTION


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INDUSTRY, INNOVATION
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SUSTAINABLE CITIES
AND COMMUNITIES


SUSTAINABLE
DEVELOPMENT
GOALS

Abstract

In today's age, when architecture can no longer ignore the finite nature of resources, building has ceased to be simply an act of pure creation and has become a necessary re-founding of fundamental principles.

The treatise examines the shift from the traditional concept of sustainability to that of regenerative design, stating that upcycling should be seen as the key method for turning the end-of-life stage of materials into a generative principle in a new tectonics of the existing. Having replaced the conventional approaches, the study outlines a future in which the act of building achieves an active balance with the resources of the biosphere.

So what are the real prerequisites for this vision to become a consolidated practice?

The investigation goes beyond mere speculation and involves a thorough analysis of the feasibility of upcycling, identifying the processes, skills, and technologies needed to put it into practice. By making a rigorous comparison between the nation's regulatory framework and the standards of excellence found in the international community, the study presents a clear picture of the current state of the art in the italian context. A detailed examination of material flows together with a study of typical case studies gives a full understanding of the real level of development of the construction supply chain and, most importantly, of the structural obstacles that are still preventing its progress. Here, a deep systemic asymmetry appears: a paradox in which the political push for a circular economy comes up against bureaucratic systems and certification procedures which remain based on the belief in virgin materials and standardized performance.

The main focus of the research then looks at the future course of the profession: *in what way must architectural practice develop in order to manage the complexity of adaptive design and circular logistics?*
The dissertation suggests a reorganisation of methodology in which the design workspace acts as a coordinating centre that brings together digital traceability, new material sources, and an aesthetic sense which can elevate the historical memory of waste. It ends by developing an organic framework of propositions that is able to bring institutional incentives into harmony with the visionary approaches of private commissions. By rejecting uncritical positivism and at the same time adopting a realistic approach that is essential for operation, the thesis presents itself as a methodological procedure for a conscious architectural practice in which obsolescence is not seen as a limitation but rather as the basis for lasting, ethical, and systematically viable beauty.

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CHAPTER ZERO

Introduction

Assumption

The current climate crisis imposes a considerable revision of the architectural discipline's production models, positioning the construction sector at the center of a complex debate on sustainability and decarbonization.

Despite international regulatory systems and environmental certification protocols having progressively enforced stringent standards for containing operational energy consumption, the global emissions balance of the building sector remains dramatically high. At a historical moment when the time available to reverse the climate-altering emission curve is severely limited, focusing exclusively on the future performance of the built artifact implies disregarding the current environmental impact generated by the extraction and production of materials for contemporary construction sites.

Faced with the manifest unsustainability of the standard linear economic model, the theoretical momentum toward material circularity has achieved widespread consensus among the scientific community. Nonetheless, current implementation practice struggles to translate this knowledge into widespread operational models. The vast majority of large-scale circular strategies are currently confined to conventional recycling operations that result in downcycling. Construction and demolition waste is subjected to industrial treatments that not only require massive energy expenditure but also cause a progressive degradation of the material's qualitative properties, declassing it to road sub-bases or inert fills.

The fundamental premise animating this research stems from the need to break down this dynamic, positioning Upcycling Architecture as its central axis. The primary impetus driving the initiation of this study lies, however, in a critical appraisal of the state of the art regarding upcycling: to date, this practice has remained confined to an elite, erudite, and exceptional dimension, frequently restricted to temporary pavilions or micro-scale interventions. In the real estate market, upcycling is still perceived by the supply chain stakeholders as an economic hazard or an aesthetic eccentricity, due to a lack of codified processes.

The research situates itself precisely within this gap, proceeding from the premise that upcycling must execute a necessary and no longer deferrable scalar leap, transitioning from a craft exception to a conventional, scalable, and industrializable practice.

To enable this transition, the challenge is not only architectural, but methodological and procedural. It is necessary to overcome the rigidity of the traditional industrial catalog and structure an approach in which the design workflow can accommodate and valorize the availability of pre-existing regional resources. The crucial passage lies in providing the designer with control and management mechanisms capable of absorbing the variability of recovered materials and integrating them within a clear and replicable logistical and decision-making iterative process.

In conclusion, the foundations of this research rest upon the conviction that sustainability can no longer be evaluated solely through the addition of technological devices or efficient installations applied to envelopes conceived according to linear logic.

Only by supplying structured operational tools capable of engaging with current performance, health and safety regulations can upcycling cease to be a niche ecological manifesto and transform into a common, accessible construction praxis fully integrated into the building processes of the future.

Thesis objectives

The overall objective of this research is to develop an integrated methodological, taxonomic, and operational framework that guides the designer in the conscious, systematic, and replicable integration of upcycling practices within contemporary architectural design.

The research does not intend to configure itself as an abstract collection of best practices or as an experimental, ephemeral installation; on the contrary, it aims to demonstrate the concrete technical and constructive feasibility of the circular approach at the building scale, critically evaluating its ecological-related success in terms of mitigating global environmental impacts as investigating its novel expressive-formal, semantic, and aesthetic potentials.

The ultimate horizon is the codification of a series of procedures that transform waste from a management constraint into a generative input of the building process, in order to make upcycling architecture a popular practic, both in Italy and beyond.

To achieve this goal, the investigation is articulated through a sequence of interconnected detailed objectives intended to resolve the primary theoretical, operative, and technological difficulties of the subject:

• Codification of replicability and performance deconstruction of avant-garde practice:
The investigation intends to demonstrate that upcycling is neither an ephemeral nor an episodic occurrence, but a structurable technological strategy. Through the critical analysis of international case studies, the objective is to abstract the empirical experience of sector leaders to render it scientifically replicable, in particular in Italy. The intention is not to describe the finished work, but to perform a technological anatomy capable of isolating detailed solutions, logistical procurement modalities, hygrothermal behaviors, and structural responses of recovered components, translating them into an abacus of open solutions available to current professional practice.

• Sistematization and cross-sectoral classification of waste flows:
A central objective of the research is to overcome the fragmentation of information concerning available residual resources. The investigation intends to structure cataloging criteria capable of unifying under common parameters both construction and demolition waste (C&D) and waste originating from external manufacturing supply chains (automotive, textile, plastic, metallurgical). The goal is to define multi-criteria assessment metrics that allow the designer to qualify ex-ante the suitability of the waste, balancing heterogeneous variables such as the geographical proximity of the resource, hygienic-sanitary safety, residual durability, and actual energy savings calculated via simplified Life Cycle Assessment (LCA).

• Validation of upcycling practice within local supply chain contexts:
The final and fundamental specific milestone consists in demonstrating the operational feasibility of the entire methodological framework within a real and territorially defined market, such as that of the Piedmont region and the Turin metropolitan area. The objective is to validate the paradigm shift: demonstrating, specifically, how a permanent project can originate and take form not from an a priori formal idea, but from the actual quantitative mapping and managerial traceability of pre-existing resources in the hinterland. The final output aims to prove, through disassembly-oriented detailing (DfD) and rigorous environmental balances, that upcycling architecture is capable of securing exceptional technical performance and a drastic reduction in embodied carbon in comparison to traditional construction practices.

Methodology

To achieve the established objectives, the study adopts a strict methodological structure of an analytical-experimental matrix. Within this approach, the design act and empirical investigation are understood as primary tools for active inquiry, the production of new knowledge, and the validation of the thesis hypotheses. The process develops in five synergistic, sequential, and closely interconnected phases, structured to transition the investigation from theoretical-normative abstraction to the codification of operational instruments applicable in professional practice.

1. COGNITIVE PHASE

Scientific, technological, and regulatory background

The first phase aims at a rigorous and systematic review of international scientific literature concerning circular economy themes applied to the built environment, industrial symbiosis, and the thermodynamics of building materials.

Concurrently, this phase examines the current regulatory framework for the management, classification, and reintroduction of waste flows into the production cycle. The investigation concentrates on European legislation and its complicated transposition into the Italian context. This framing is preliminary and indispensable for mapping the bureaucratic barriers, legal issues, and real market opportunities that a designer faces within the national panorama.

2. CRITICAL-TAXONOMIC PHASE

Technological deconstruction of case studies

The second phase initiates empirical investigation through the selection, cataloging, and analytical documentation of paradigmatic architectural projects at the international level, identified as methodological excellences in the embedding of upcycled components. Moving beyond a purely descriptive or formal approach, the research executes a genuine technological anatomy of the selected building organisms. The buildings are ideally traced back to their sub-systemic components (load-bearing structure, insulating envelope, internal partitions, external cladding systems). The output of this phase resides in the formulation of a systematic taxonomy of materials and construction details oriented toward connection reversibility.

3. FIELD RESEARCH

The interview campaign and the Copenhagen site visit

The operational, empirical, and interactive core of the thesis develops during this third phase, conceived as a period of direct qualitative field investigation. The objective is to validate the data derived from scientific literature through direct comparison with advanced European professional practice. This phase occurred in two tightly synergistic moments:

THE COPENHAGEN SITE VISIT:

Assumed as an avant-garde urban, social, and experimental context for public policies on the circular economy and for the territorial presence of a mature ecosystem for the storage, processing, and commercialization of recovered materials. Direct surveying, photographic analysis, and in-situ observation of Danish architecture and logistical hubs enabled the direct evaluation of their tectonic quality, aging durability, and effective formal inclusion into the consolidated urban fabric.

THE INTERVIEW CAMPAIGN:

Conducted through direct dialogue with technical referents, research directors, and designers from four internationally renowned practices, recognized globally as pioneers in the architectural upcycling sector:

- GXN (Denmark): The research and innovation unit of the Danish practice 3XN, focused on developing new biological and circular materials and codifying Design for Disassembly strategies applied to complex, large-scale projects.
- Superuse Studio (the Netherlands): Historical pioneers of design workflow inversion and creators of platforms and tools for the geo-localized mapping of waste resources at urban and regional scales.
- Park Associati (Italy): A Milanese excellence actively conducting internal research and field experimentation to integrate the logics of the circular economy, material passports, and traceability within the Italian regulatory, procedural, and real estate framework.
- Roncelli Studio (Denmark/Italy): A transnational design and experimental laboratory focused on the tectonics of waste, material resignification in contexts of resource scarcity, and the design of non-conventional building components starting from industrial waste flows.

4. ANALYTICAL-DEDUCTIVE PHASE

Extrapolation of Lessons Learned and critical barrier analysis

This phase operates as a critical hinge among empirical field investigation and subsequent operational synthesis. Through the transcription, categorization, and comparative examination of qualitative data gathered during site visits and direct interviews, the primary lessons learned are extrapolated.

The objective is to systematically map key success factors and, above all, the critical issues (technological, performance-related, logistical, economic, and regulatory) that architectural practices confront daily in the upcycling process. Nodal issues are critically analyzed, such as the certification of thermomechanical performance and fire resistance for materials lacking traditional CE marking; the unpredictability and quantitative inconstancy of supply chains; the estimation and management of increased costs and construction timelines linked to selective demolition in comparison to traditional demolition; and cultural resistances or insurance barriers from clients and contractors. This effort transforms the empirical experiences of the practices into structured and theorized scientific knowledge.

5. SYNTHESIS AND OUTPUT PHASE

Proposal of the Operational Protocol

The concluding act of the research methodology lies in the convergence of theoretical, normative, taxonomic, and qualitative data collected within an original proposal for a methodological-operational protocol.

This tool is configured as a procedural guideline and multi-criteria decision matrix designed to support the designer's activity during the early phases of the building process (concept and definitive design), a moment when technological and material choices exert the maximum impact on the environmental balance of the artifact. The protocol operationally synthesizes the rules of design inversion.

It defines a clear iterative process to:

- Inventory, trace, and map local waste flows (zero-kilometer approach).
- Ex-ante evaluate the technical, structural, and hygienic-sanitary compatibility of the recovered component within the strict frameworks of Italian and European regulations.
- Establish constructive interface details prioritizing dry connections and disassemblability logics.

The protocol thus offers itself as a concrete, replicable, and expandable tool, aimed at transitioning upcycling from a pioneering and artisanal practice to a structured and industrializable methodology.

CHAPTER ONE

01

From Sustainability to Regenerative Design

1.1. From Linear to Circular Design

The world of design is experiencing an unprecedented paradigm shift, driven by the immediate need to reformulate the relationship between human activities and natural systems.

For a long time, the concept of sustainability represented our society's highest ecological aspiration, serving as a theoretical and practical beacon intended to reduce the side effects of industrial development. However, in an era distinguished by profound climate change and biodiversity loss, simply keeping the status quo is inadequate. Confining our efforts to slowing down the planet's deterioration is no longer enough; it is imperative to reverse course.

The evolution toward Regenerative Design stems from this awareness, a perspective that goes beyond the logic of neutrality to embrace positive impact. While traditional sustainability aims for zero impact, regenerative design proposes itself as an active force of renewal and healing.

This radical transition cannot, however, take place without a radical deconstruction of the economic and production models that have characterized the Anthropocene.

The fulcrum of this metamorphosis lies in the crucial transition from linear to circular design.

Rethinking material flows, extending the life cycle of products, and enhancing disassemblability and upcycling represent the key steps to dismantle the linearity of consumption.



Fig. 1_Copenhill - BIG, Copenhagen, 2019. Source: *big.dk*

The limit of mitigation

For several decades, the contemporary architectural debate has remained bound to an interpretive ambiguity driven by the predominance of the **sustainability** paradigm. This concept, conceived to preserve natural capital, has been reduced in practical and regulatory applications to a mere strategy for mitigating environmental damage.

In the building sector, this translates into an exasperated pursuit of operational technological efficiency (the reduction of energy consumption and emissions within thresholds codified by protocols such as LEED, BREEAM, or ITACA). However, this "less harmful" architecture fails to address the structural roots of the ecological crisis, limiting itself to developing the status quo without radically questioning its extractive and linear foundations.

In an era of irreversible climate crisis and raw material depletion, the Net Zero objective (Hickel, 2020) is insufficient. Sustainability interpreted as eco-efficiency has failed to resolve the consumption paradox: optimization often does not contract resource extraction, but instead shifts its impact or legitimizes consumption through greenwashing.

As highlighted by scholars such as Bill Reed (2007), conventional sustainability pursues a static equilibrium, a "thermal zero" incapable of restoring the resilience of already degraded ecosystems; architectural action is confined to managing decline in bureaucratically acceptable forms.

The intrinsic limitation of such a vision consists in its mechanistic and fragmentary matrix, whereby the building is analyzed as an isolated thermal machine, systematically ignoring the ecological debt accumulated throughout the entire lifecycle of material components. Designing with a perspective of neutrality frequently means omitting the destructive impact of extraction phases and the dissipation of embodied energy (Embodied Carbon) that occurs whenever a component is demolished rather than regenerated.

A fundamental critical question thus emerges:

Is it possible to speak of sustainability if the act of building continues to be subordinated to a linear supply chain that transforms resources into waste, albeit through technically more efficient processes?

Conventional sustainability has fostered the conviction that increasing thermal insulation thickness, integrating photovoltaic systems, or employing low-emissivity glazing could, on their own, resolve a crisis that is intrinsically systemic, political, and metabolic in nature. Such an approach has generated an architecture of surfaces, wherein point-source energy performance conceals the poverty of material cycles and the absence of a strategic vision for the end-of-life stage of the building organism.

Overcoming the logic of mitigation therefore implies accepting a new responsibility for architecture, which can no longer define itself as a neutral or passive activity. It must assume the ethical burden of actively repairing the alterations inflicted upon the biosphere, reconfiguring the construction site no longer as a place of resource consumption, but as a stronghold of territorial healing.

The objective no longer lies in the mere subtractive calculation of residual resources, but rather in the design of buildings capable of acting analogously to plant organisms: structures able to purify the hydrosphere, sequester carbon, and, primarily, offer their own matter as nourishment for upcoming urban cycles through **upcycling** practices. In this perspective, the aesthetic quality of architecture becomes inextricably linked to the concept of climate justice: a built artifact that ignores the destiny of its material components represents, within the regenerative paradigm, a design and ontological failure.

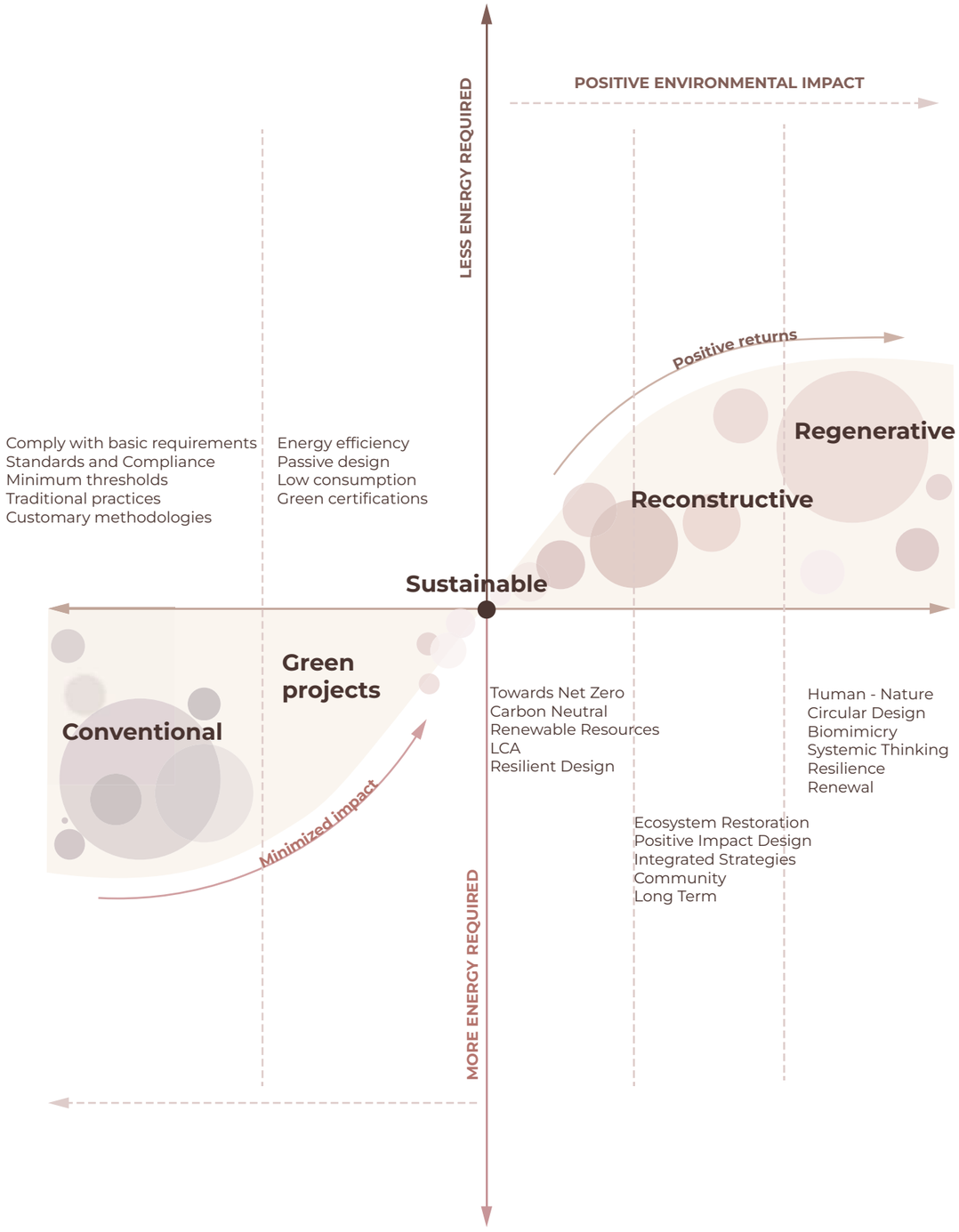


Fig. 2_Paradigm shift: from conventional design to a regenerative design approach. Source: *Reed, B. (2007). Shifting from 'sustainable' to 'regenerative' design. Building Research & Information.*

The paradox of the “new green”

For decades, the debate on sustainability in architecture has been almost entirely monopolized by the concept of plant engineering efficiency and thermal insulation.

This approach, although necessary, has focused in a myopic and dangerously unbalanced manner on reducing CO_2 emissions exclusively during the building’s operational phase (so-called Operational Carbon), the energy required for daily heating, cooling, and lighting. However, this purely operational vision systematically ignores the critical and devastating “phase zero”: that massive and irreversible release of carbon occurring long before a user crosses the threshold of a building or presses a switch, tied to raw natural resource extraction, high-temperature industrial refining, global-scale transportation, and heavy construction site logistics.

This gives rise to what might be defined as the **paradox of the “new green”**: the illusion that radical building replacement is the only realistic path for ecological transition. Replacing an existing building (even if energetically inefficient and structurally dated according to contemporary standards) with a new, ultra-high-performance structure such as an NZEB (Nearly Zero Energy Building) triggers an emission debt mechanism that frequently escapes the simplified analyses of current certification protocols.

The new artifact, no matter how salvific its future operation may appear, is born with an emission expenditure so high that it may require thirty to eighty years of flawless operation merely to repay the carbon debt generated by its own construction and the violent demolition of the pre-existing structure.

At a historical juncture wherein emissions reductions must be immediate to prevent the crossing of climate tipping points forecasted by IPCC models (Intergovernmental Panel on Climate Change, 2021) for the coming two decades, waiting mid-century to reach the emission break-even point is a temporal luxury and a thermodynamic hazard that the planet can no longer absorb.

Critical Life Cycle Assessment (LCA) applied to the built environment reveals data that brutally overturns traditional design hierarchies: embodied carbon can today account for up to 50–70% of a building’s total emissions over a fifty-year lifecycle (World Green Building Council, 2019).

This figure is paradoxically destined to increase as the electrical grid decarbonizes and buildings become more efficient in their operation (RICS, 2018): the more we decrease Operational Carbon through technology, the more the relative weight of carbon trapped within structural materials becomes the distinguishing variable between a genuinely sustainable project and an operation of refined greenwashing on an urban scale.

Demolishing an existing building thus constitutes an act of thermodynamical dissipation: it means instantaneously pulverizing all the energetic value already expended, sealed, and crystallized within structural materials through decades of industrial history. It is the forced transformation of an immobile climatic asset (a carbon reserve that has already paid its price to the atmosphere and now functions as a secure warehouse) into an immediate and catastrophic atmospheric liability. In this new light, the sustainable design paradigm must undergo a total and definitive polarity shift: true ecological architecture is no longer necessarily that which promises, via captivating renderings, vertical forests, and hyper-technological glazing, to consume fewer resources in a hypothetical future, but rather that which is capable of guarding, defending, and preserving the greatest possible amount of emissions already incurred in the past.

This critique directly implicates state incentive policies, which frequently favor demolition and reconstruction (scrape and rebuild) over profound energy retrofit, ignoring the reality that the best energy class is that of the building that does not need to be constructed from scratch.

Structural conservation, the upcycling of the existing, and erudite maintenance represent the most advanced, radical, and scientifically founded strategies for short-term climate mitigation.

Within this scenario, the conservation of embodied energy ceases to be a technicality for specialists. It becomes the only true ethical currency for biospheric survival, elevating the existing building to the most powerful and immediate energetic shield humanity possesses.

The challenge is therefore not to build the future, but to prevent the construction of the future from destroying the present through new embodied emissions.



Fig. 3_ Demolition of the Piazzale Lugano “monster,” 2020. Source: *urbanlife.org*



Fig. 4_Bovenbouwwerkplaats - Studioninedots, Utrecht, 2022. Source: *studioninedots.nl - Sebastian van Damme*

The hierarchy of emissive value: structure and envelope

The hierarchy of emissive value within an architectural organism reflects a strong and inescapable polarization between the physics of materials and the history of the heavy industrial processes that have influenced modernity.

If we look at the city no longer as a collection of forms, but as an immense deposit of crystallized energy, we must recognize that the densest, most stable, and dangerously difficult-to-reverse carbon mine resides invariably in the **primary structural elements**: deep foundations, the column grid, beam frameworks, load-bearing partitions, and complex floor systems. This structural backbone does not represent only the static support necessary to counteract the force of gravity and guarantee the safety of inhabitants, but constitutes an immense and silent accumulation of ancestral energy; energy that was extracted from the bowels of the earth, refined in energy-intensive facilities, transported on a global scale, and finally released into the atmosphere in the form of climate-altering gases decades ago, at the exact moment of the thermodynamic genesis of the artifact.

The materials protagonists of this energy stratification, namely reinforced concrete and structural steel, are the primary responsible for the vast majority of initial anthropogenic emissions in the construction sector. This negative primacy is due to the extremely high chemical and thermal intensity of their production cycles, processes operating on near-geological timescales and temperatures. Consider the production of Portland cement, where the decarbonation of limestone within rotary kilns releases huge amounts of CO_2 not only as a consequence of burning fossil fuels to reach 1450°C, but as an intrinsic and inescapable chemical byproduct of transforming calcium carbonate into calcium oxide (clinker) (IPCC, 2006; van Oss & Padovani, 2002). Similarly, primary steelmaking relies on blast furnaces that consume massive quantities of coking coal, leaving a carbon footprint imprinted in the metal throughout its technical life.

When we observe a reinforced concrete skeleton, perhaps dating back to the 1960s or 1970s and often dismissed as ugly or functionally obsolete, we are not simply looking at a mass of cold gray matter; we are observing an emissive capital already amortized by the planet, a debt the Earth has already laboriously absorbed. Demolishing it today constitutes an act of irrevocable thermodynamic nihilism: it renders futile that prior environmental sacrifice, zeroing out the material's energy memory and obliging the biosphere to bear the burden of a new, violent extractive and production cycle to replace with new concrete what was already statically efficient and functional. It is a cruel paradox: destroying carbon already emitted to emit more in the name of a supposed modernity.

Unlike the load-bearing core, the **building envelope** (composed of window frames, curtain walls, insulating layers, and waterproofing membranes) possesses opposed thermodynamic and chronological characteristics. Such elements belong to what Stewart Brand defines as "shearing layers" (1994), subject to short life cycles (often under 25 years) tied to technical obsolescence, polymer degradation, or the radical shift in thermal performance required by current regulations. Although their replacement inevitably generates new embodied carbon, their volumetric and chemical impact is several orders of magnitude lower than the critical mass of the structural framework.

Herein lies the crucial node and crucial opportunity of structural upcycling: while it is technically and ecologically imperative to intervene on the envelope to decrease operational consumption, it is almost invariably a fatal bioclimatic error to demolish the structure that supports it. The major challenge that the regenerative designer must embrace is therefore that of executing a true component surgery, a discipline requiring the nearly clinical capacity to separate what is destined to change cyclically from what must endure as a tectonic constant. One must boldly update surface layers (skin, building services, movable partitions) to guarantee the highest standards of comfort and performance while thoroughly preserving the structural core to honor the carbon already embodied.

Maintaining this emissive critical mass in situ radically transforms the ontological and political status of the urban pre-existence. In this scenario, the existing building ceases to be perceived exclusively as an energy accumulation and is finally recognized as a climatic pillar. The structure becomes a genuine carbon vault that prevents the emission of hundreds or thousands of tons of new CO_2 that would inevitably be generated for the production of virgin concrete and steel required by total reconstruction.

Structural upcycling thus elevates material stability to a supreme ethical value: it is no longer merely a question of conserving architectural form for historical, nostalgic, or collective memory reasons, but of administering with wisdom and scientific severity a deposit of expended energy that the Earth no longer has the capacity to replicate without risking systemic collapse.

Every reused beam is proof that human cleverness can stop bulimically consuming the future and begin caring for and valorizing the material heritage of the past. The value of a building, therefore, must no longer be measured by what it produces or how much it consumes in its daily operation, but by the amount of destruction and new emissions that its continued existence successfully prevents.

The invisible cost of demolition

The act of demolition, frequently considered within the real estate sector as a necessary cleanup operation or an inevitable prelude to urban regeneration, is, in reality, a thermodynamic trauma that generates a dual and irreversible loss: the destruction of material capital and, above all, a dramatic and underestimated loss of climatic time.

At a time when the success of environmental policies is measured by the speed of anthropogenic emissions reduction, tearing down an existing building means deliberately ignoring the physics of climate. When an artifact is razed to the ground, the climate-altering emissions tied to its original construction cease to be an amortized energy investment and instantly transform into sunk costs. At that precise moment, the decision to replace it with new construction immediately releases a critical mass of CO_2 (the so-called Upfront Embodied Carbon) into the atmosphere, precisely within the most dangerous time window for the ecosystem stability.

Much of European and global building legislation incentivizes the replacement of inefficient buildings with new NZEB (Nearly Zero Energy Building) complexes, relying on the fallacious assumption that future operational savings (tomorrow's reduced consumption) will compensate for the brutal impact of today's construction (European Parliament & Council of the European Union, 2024). However, this vision ignores the immediacy factor. If climate science, through IPCC reports, demands drastic and unprecedented reductions by 2030 and 2050 to avoid crossing tipping points, we cannot afford the luxury of generating a massive emission peak in the present in the hope of recovering it forty or sixty years from now through plant efficiency. Building ex novo today, even by resorting to state-of-the-art bio-based materials, produces a carbon footprint that the global atmospheric budget can no longer absorb without catastrophically accelerating global warming.

In this scenario, deep conservation and the upcycling of existing materials cease to be purely aesthetic choices or demands for historical preservation, and instead become an effective mechanism for sequestering anthropogenic carbon. By maintaining materials in their current state of order and molecular aggregation, we not only avoid the production of new virgin matter, but we avert the release of greenhouse gases stemming from mechanical fragmentation processes, landfill transport, and the treatment of construction and demolition waste, which today account for approximately one-third of total global waste generation (UNEP, 2024). The building that remains standing is not simply an architectural object: it is, effectively, carbon that does not enter the atmosphere.

Selective deconstruction and the reuse of structural components (steel columns, concrete floor slabs, timber beams) thus emerge as the only building strategies genuinely capable of having a positive, or at least neutral, impact on the emissions curve in the short term. While Carbon Capture and Storage technologies remain experimental, expensive, and extremely energy-intensive, **upcycling architecture offers a technology that is already mature and available:** utilizing the built environment as a bank of already sequestered carbon.

Ignoring the temporal penalty of demolition means condemning the planet to a thermal peak in the present in exchange for an uncertain and belated benefit in the remote future. The only truly sustainable building is the one that already exists, and the principled task of contemporary design is to extend its useful life through the ingenuity of upcycling, honoring the energy debt we contracted with the past so as not to mortgage the future definitively.

The building as carbon capital

Embedding Embodied Carbon into the decision-making and regulatory processes of urban transformation demands a radical transition in real estate appraisal: a definitive shift from a purely financial accounting system, anchored to the short cycles of profit and land rent, to a bioscenic and thermodynamic accounting of architectural value.

If we accept the indisputable scientific reality that the atmosphere's capacity to absorb additional CO_2 without triggering catastrophic climate feedback loops is a finite resource, then every single kilogram of carbon already sealed within an existing column assumes an inestimable intrinsic value.

The adoption of this vision brings profits that extend far beyond only environmental metrics, impacting the social and economic spheres:

- **Mitigation of "Emission Shock":**
Unlike new constructions that promise benefits over 50 years, structural upcycling acts in the hic et nunc. By avoiding demolition, the initial emission peak is nullified, enabling compliance with the 2030 European targets that new building methods risk compromising.

- **Democratisation of Preservation:**
By shifting value from aesthetic merit to carbon density, protection is extended to ordinary and peripheral buildings. This reduces demolition-driven gentrification, preserving the existing social fabric alongside its material backbone.

- **Resilience of the Local Supply Chain:**
Recovering carbon capital requires high specialisation intensity rather than high virgin material intensity. This supports the local economy and artisan workforce, reducing dependence on global steel and cement supply chains, which are frequently subject to geopolitical instability.

Despite its scientific validity, the carbon capital approach clashes with structural resistances and potential crucial pitfalls that cannot be ignored:

- **Asymmetry of Economic Costs:**
Currently, the market penalises recovery. Dismantling, reinforcing, and retrofitting an existing structure often costs more than demolishing and rebuilding. Without a Carbon Tax on new materials, the carbon capital of the existing stock will remain a non-competitive theoretical value.

- **Complexity of Calculation and Certification:**
Determining the exact amount of embodied carbon in a 1960s building is a complex operation subject to margins of error. The lack of reliable historical databases concerning the materials of that era makes bioscenic accounting more difficult to standardize than the linear calculation of new construction, leaving it open to possible data manipulation.

To overcome these limitations, a direct challenge to government incentive methods is necessary.
We must stop accepting the notion that a new "Class A" building is intrinsically superior to a "Class C" retrofit if the former generated 500 tons of CO_2 to be erected.

Tomorrow's architecture must be, above all, an architecture of **extractive parsimony.** Only through integrating Embodied Carbon calculations from the initial design competition onward, transforming it into a binding parameter, can we halt the drift of systematic building substitution.

The designer's challenge is no longer to add new form to the world, but to act as a curator of carbon cycles, capable of regenerating beauty through the recognition of the energy value already deposited within our streets. Only thus will the city cease to be a linear engine of destruction and become a homeostatic ecosystem, where inherited carbon capital is valorised and passed down, rather than barbarically burned on the altar of a false idea of progress.

Regenerative Design

While classical sustainability (stemming from a twentieth-century industrial vision) establishes the achievement of a static, conservative, and defensive state of equilibrium (the so-called “zero impact”) as its objective, **regeneration** shifts the horizon toward the creation of dynamic, evolutionary, and enterprising systems.
In this new scenario, architecture is no longer called upon to be a passively neutral entity. Still, it must configure itself as a game-changing device capable of intentionally and measurably improving the conditions of the ecosystems and communities in which it is embedded

The regenerative approach demands the reconsideration of the building artifact as a true living organism, a complex and symbiotic exchange node integrated within a perennially shifting urban and environmental metabolism.

In this perspective, architecture ceases to be perceived as a subtractive, foreign body relative to the biosphere, transforming instead into an active catalyst of ecological, social, and biological value. The building is no longer the ultimate terminal of a linear extractive process, but a transit station for matter, engineered to nourish and regenerate the surrounding territorial system.

This reversal of course requires a radical mutation in the language and tools of design: it is no longer sufficient to reference atomized parameters such as thermal transmittance or insulation performance; rather, it is necessary to reason in terms of ecosystem services. Much like a biological organism that dialectically interacts with its habitat, the regenerative building must be conceived as a structure capable of actively sequestering carbon, filtering and phytopurifying stormwater, fostering urban biodiversity through biodynamic envelopes, and producing an energy surplus to be redistributed within the societal framework.

In this sense, regeneration is not a static milestone to be certified once and for all, but an evolutionary and adaptive process: architecture becomes a living infrastructure that grows, learns, and transforms in symbiosis with the biosphere, overcoming the dichotomy between the natural and the artificial.

The inversion of sustainability lies precisely in recognizing that architecture is never a finished, static, or immutable product, but a temporary phase of matter in perpetual metamorphosis, which the architect is tasked with ferrying from one cycle to the next.

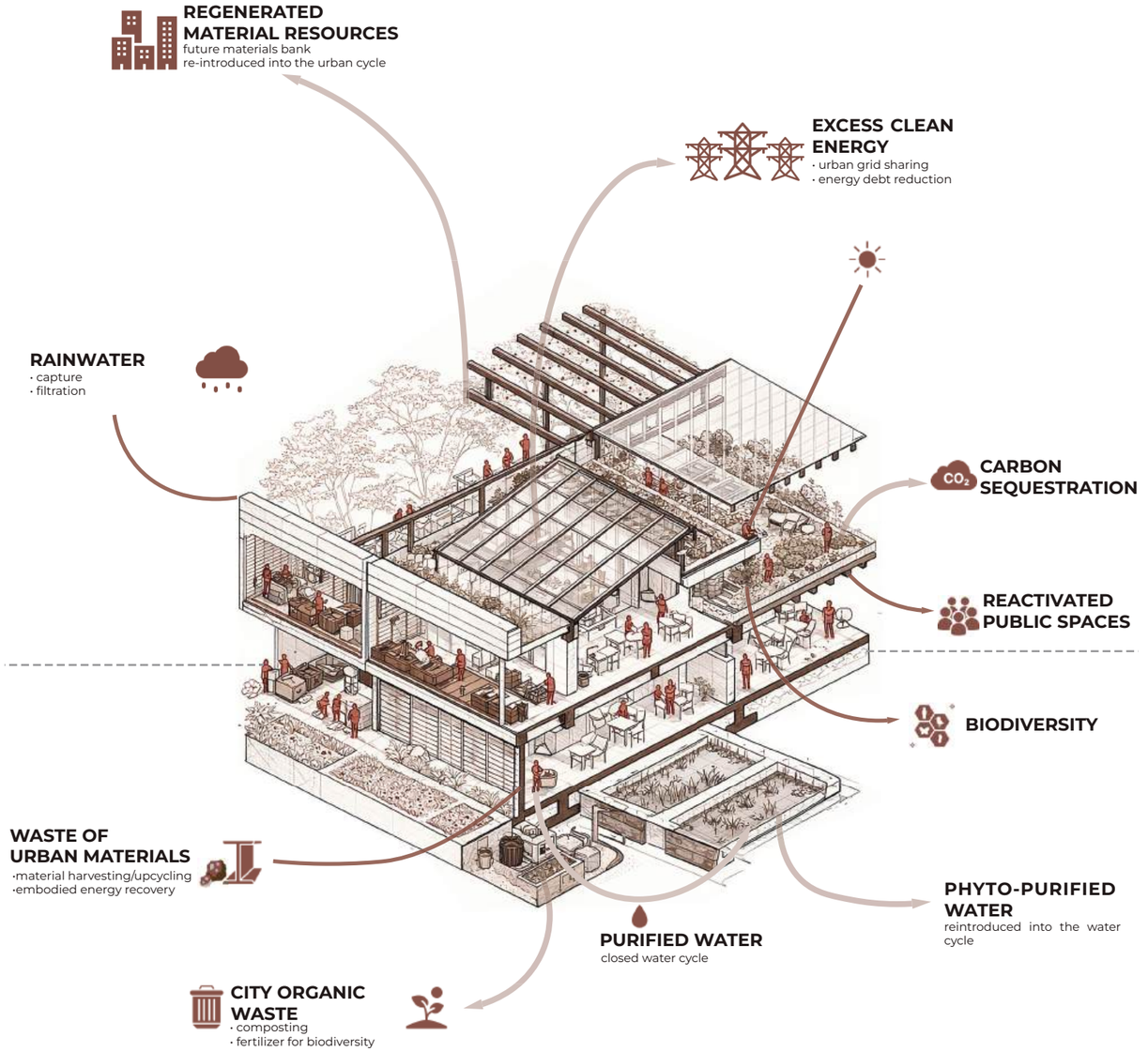


Fig. 5_The regenerative approach. Source: *personal processing*

1.2. Circularity taxonomies and upcycling scales

The transition from a linear economy to a circular model requires considerable revision to the architectural design of resource management modalities and existing built heritage. In this context, it is no longer sufficient to speak generically of “sustainability”; rather, it is necessary to critically distinguish among the various strategies that contribute to reducing environmental impacts. A rigorous definition and precise terminological distinctions among recycling, adaptive reuse, and upcycling are required to critically analyze contemporary strategies and the management of materials and building heritage within the framework of architectural sustainability.

These practices, while belonging to the same semantic field linked to resource optimization, describe profoundly different processes in terms of intervention scale, degree of material transformation, and generated value.

In common parlance, these terms are frequently employed interchangeably, generating conceptual ambiguities which risk compromising the correct interpretation of design strategies and environmental legislation. In reality, each practice implies particular operational modalities, distinct relationships with the life cycle of materials and the building, and divergent outcomes in terms of energy consumption, resource conservation, waste production, and the cultural or functional value of the final result.

Terminological clarity establishes itself here as an indispensable methodological premise for contextualizing architecture within the ecological transition. A rigorous understanding of such categories is the sole instrument capable of guiding a conscious evaluation of environmental impacts, distinguishing purely mitigative interventions from those capable of generating effective added value, whether material, functional, or symbolic.



Fig. 6_ Kampung Admiralty - Ramboll Studio Dreiseitl and WOHA, Singapore, 2017. Source: *archdaily.com - Patrick Bingham-Hall*

Recycling

The concept of **recycling** has historically been a key pillar of material management strategies at the end of their lifecycle, emerging as the most structured industrial response to the waste crisis of the twentieth century.

From a strictly technical and regulatory standpoint, it is defined (according to the 2013 Ellen MacArthur Foundation report) as:

"a recovery operation by which waste materials are processed into products, materials or substances whether for the former or other purposes"

Such a process, according to the parameters defined by the Waste Framework Directive 2008/98/EC (European Commission, 2008), presupposes an intense and frequently irreversible manipulation of matter: the waste loses its morphological, tectonic, and functional identity to be reduced to secondary raw material through mechanical, chemical, or thermal processes of varying intensity. Although it is a consolidated and indispensable practice for contemporary urban metabolism, from the perspective of value preservation, recycling implies the definitive rupture of the structural and technical bonds of the native component, zeroing out the value of the labor and energy previously invested in its conformation.

Within contemporary architectural and engineering literature, the efficacy of recycling is frequently analyzed critically through the lens of thermodynamics and systems theory. As highlighted with extreme clarity by McDonough and Braungart (2002), an intrinsic limitation of this practice is the phenomenon of **downcycling**.

In many industrial flows, the degradation of fibers (in the case of polymers or paper) or the presence of contaminants and chemical binders during treatment (in the case of building composite materials) entails an irreversible loss of quality. The result is a material that, while technically recovered, does not possess the same mechanical, chemical, or aesthetic properties as virgin material, thus being inexorably declassified to less noble and less resistant applications.

In the building sector, the most emblematic and systemic example of this qualitative failure is represented by structural concrete: once crushed, the resulting debris is often re-employed exclusively as aggregate for road sub-bases or mass fills. In this scenario, while formally closing the loop of matter and diverting volumes from landfills, a massive dissipation of original qualitative and performance value occurs. The material shifts from a load-bearing and structural function to a mere infill function, still requiring a considerable power input for crushing, screening, and transportation operations, which frequently risk rendering the environmental balance less advantageous than perceived.

Despite these criticalities, integrating recycled material flows (especially ferrous metals, glass, and certain high-density polymers) has become a fundamental strategy for reducing the embodied energy of buildings. According to the latest analyses by Milad et al. (2025), the employment of advanced protocols for incorporating quality recycled aggregates and regenerated metal components no longer represents merely a practice of green branding or an expedient for obtaining certification credits (such as LEED or BREEAM), but a structural necessity to guarantee the strength of modern infrastructures in an increasingly volatile raw materials market. The authors highlight how the sustainability of a contemporary architectural work depends directly on the construction supply chain's capacity to absorb post-consumer materials, drastically reducing extractive pressure on natural resources and minimizing the volume of construction and demolition waste, which today accounts for approximately one-third of the total mass of waste produced globally.

Nevertheless, when studied in light of the most advanced paradigms of the Circular Economy, recycling must not be considered the definitive solution to the problem of resource consumption, but rather the ultimate useful resource within a complex hierarchy of value. The primary contradiction of recycling consists in its energy balance and the risk of generating a false sense of environmental security. Unlike more conservative and direct strategies, processing discarded matter into secondary raw material frequently requires heavy and power-consuming industrial processes that can partially, or sometimes totally, invalidate the environmental benefit obtained in terms of CO_2 emissions.

Therefore, the methodological challenge for contemporary architectural design consists in calibrating the use of recycling so that the saving of virgin matter is supported by a rigorous Life Cycle Assessment (LCA), avoiding the promotion of production cycles that, while recycling, continue to dissipate qualitative value and design-related beauty. Recycling must consequently be understood as an outer loop of circularity, a solution to be activated only when the integrity of the component or its direct repurposing is no longer technically feasible. Although it constitutes the backbone of waste management on an urban scale, recycling by no means exhausts the potential of discarded matter. On the contrary, precisely where recycling fails to maintain value, upcycling appears as the most ambitious and intellectual design response: a strategy capable of reversing the downward parabola of downcycling and transforming the entropy of waste into a new order of visual and structural value.

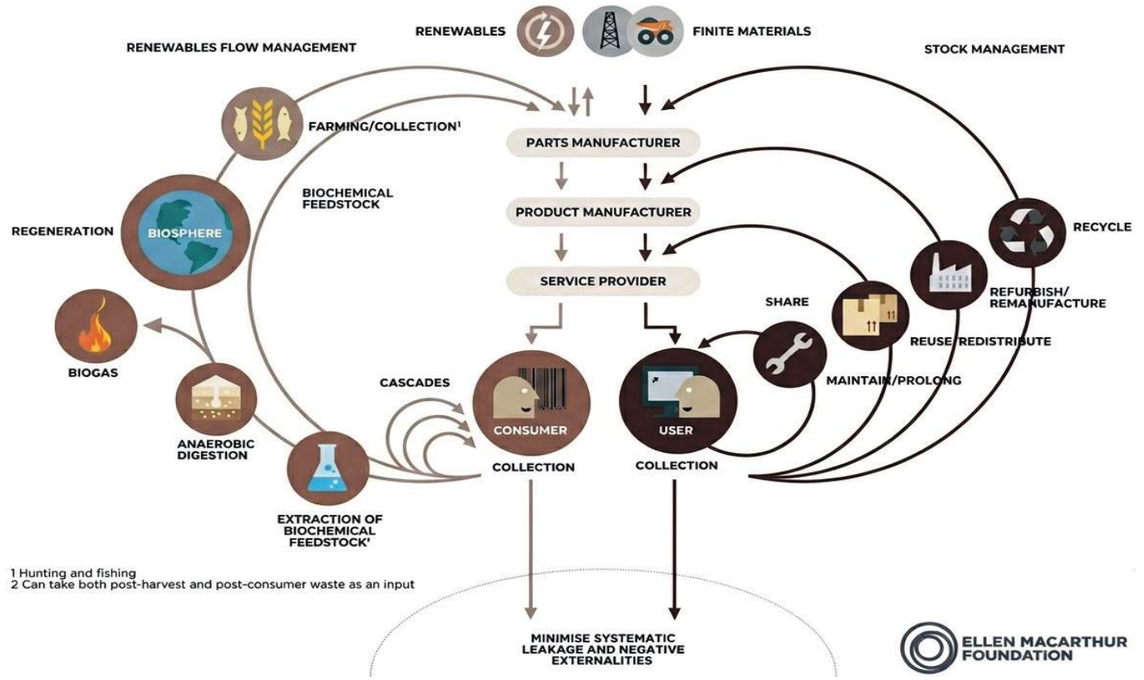


Fig. 5_ *Circular economy system diagram*. Source: Ellen MacArthur Foundation, February 2019 - based on Brungart & McDonough, Cardle to Cradle (C2C).

Reuse

The concept of **reuse** occupies a position of hierarchical preeminence within the circular economy paradigm, configuring itself as a material flow management strategy vastly superior to recycling. While the latter presupposes molecular breakdown and the destruction of the artifact for raw material recovery (an operation entailing inevitable entropic dispersion), reuse aims to iterate a component's or entire system's lifecycle while conserving its morphology, mechanical performance, and chemical-physical properties virtually unaltered.

According to the taxonomy defined by the Ellen MacArthur Foundation, reuse represents the inner loop of the circular system (Ellen MacArthur Foundation, 2013): the efficiency of the model is directly proportional to the preservation of the product's original state, since the lesser the transformation required, the lower the expenditure of energy and resources for its reintroduction into the economic and productive cycle.

Within the architectural and technological sphere, this practice is expressed through the recovery of construction elements (such as structural steel beams, timber components, wall panels, or envelope systems) extracted via **selective deconstruction processes.** Different from traditional demolition, which reduces the building to a mass of undifferentiated and declassified debris, deconstruction preserves the functional integrity of individual elements, recognizing in them a value that exceeds the simple summation of matter. The material is therefore not recycled through high-emission industrial processes, but is metabolized within the new intervention in its existing geometrical arrangement. The efficacy of reuse resides precisely in the capacity to preserve the added value embodied in the finished product: as highlighted in the studies of Gorgolewski (2017), resorting to pre-existing components enables the complete elimination of the primary energy required for the production of new materials, drastically cutting CO_2 emissions tied to the manufacturing phase.

From a methodological standpoint, reuse can unfold in two complementary directions: **compliant reuse**, which keeps the original function of the component (e.g., a metal column resuming a load-bearing function), and **repurposing**, which provides for a change in intended use through creative reinterpretation (a beam transforming into a piece of furniture or part of a facade system).

In both cases, the design approach must evolve toward the paradigm of **Design for Disassembly (DfD)**, as suggested by Baker-Brown's research (2017). Conceiving the building no longer as a static and monolithic object, but as a stratified and reversible "Materials Bank," supported by digital traceability tools such as Materials Passports, makes it possible to transform the existing building stock into a resource readily available for future generations. This drastically mitigates dependence on the extractive industry and reduces the volume of construction and demolition waste (C&D waste), which today represents one of the primary environmental criticalities on a global scale.

In parallel with component reuse, the complex strategy of **Adaptive Reuse** develops, operating at the macro-scale of the building organism or the urban precinct. This practice intervenes on complexes that have exhausted their original function (frequently due to socio-economic or technological shifts) but retain a material, historical, and social capital susceptible to functional transformation. According to Plevoets and Van Cleempoel (2019), adaptive reuse must not be interpreted as mere maintenance or passive conservative restoration, but rather as a creative process of metamorphosis that extends the useful life of the artifact while preserving its structural characteristics and external envelope. Such a practice is founded upon the valorization of the embodied energy already present in the built environment, avoiding the massive environmental impact stemming from demolition and subsequent reconstruction ex novo. The building is treated as a dynamic and resilient resource, capable of accommodating contemporary functional programs (such as the conversion of former industrial complexes into cultural or residential hubs) without producing new land consumption and without dissipating the place's identity.

Scientific literature emphasizes that adaptive reuse also acts as a catalyst for communal and economic sustainability: as argued by Conejos et al. (2014), preserving architecture's physical identity contributes to urban resilience, keeping the historical memory of places alive and mitigating gentrification through targeted regeneration interventions.

Ultimately, adaptive reuse transforms the physical limitation of the existing into an opportunity for typological and linguistic innovation, establishing itself as the indispensable link between the preservation of architectural memory and the immediate need of the ecological transition.



Fig. 7_ Adaptive reuse in the project Urban Rigger - BIG, Copenhagen, 2016. Source: *urbanrigger.com*

Upcycling

The concept of **upcycling**, often translated as “super-reuse” or “creative reuse”, does not simply represent an additional option within the catalog of ecological best practices; rather, it constitutes the most advanced, ambitious, and intellectually dense approach within the hierarchy of circularity. It acts as the methodological core of this treatise and, more broadly, of the entire regenerative strategy applied to the built environment of the twenty-first century.

Unlike conventional recovery practices, upcycling is distinguished by its explicit and systemic intent to increase value (material, functional, economic, and, above all, semantic) compared to the original state of the waste element.
Although the term was originally coined by Reiner Pilz in 1994 (Pilz, 1994) to describe industrial waste management that does not degrade its intrinsic value, it found its complete theoretical formulation and global resonance thanks to the contributions of Gunter Pauli and the Cradle to Cradle philosophy theorized by William McDonough and Michael Braungart in 2002.

Within this doctrinal framework, upcycling is elevated to a tool that overturns the downward parabola typical of the linear economy, where matter is destined for progressive obsolescence and loss of potential. While the traditional cycle operates predominantly through downcycling processes (entailing a degradation of the intrinsic physical-chemical properties of matter due to invasive industrial treatments such as remelting, shredding, or chemical decomposition), upcycling aims to preserve the physical integrity and embodied energy of the object, ennobling it through design innovation and a new tectonic sensibility.

In this sense, waste is never considered refuse to be disposed of or destroyed to recover its base components in a degraded form, but rather a precious resource whose memory, patina, imperfection, and existing form become the heuristic starting point for a superior configuration of use. As highlighted by Szaky in 2014, the critical passage in upcycling lies in the ontological overcoming of the very idea of garbage, replacing it with a systemic vision wherein every output of a process becomes a valuable input for another, without passing through phases of violent thermodynamic decomposition that entail further and massive energy inputs.

In the architectural sphere, upcycling translates into a tectonic and semantic practice of extreme sophistication. Existing construction materials, industrial waste foreign to the building supply chain, or obsolete technological components are reinterpreted as structural elements, facade cladding systems, internal partitions, or high-end furnishing details. This vision transcends simple functional reuse: the material is not simply employed for a contingent economic necessity, but undergoes an aesthetic and performance evolution that raises its status within the architectural work, changing what was marginal or invisible into a central element of the design language.

According to research by Bridgens et al. (2018), upcycling promotes a “**Material-led design**,” inverting the traditional creative process. In this paradigm, the designer’s creativity does not impose an a priori form onto inert matter. Still, it has to adapt, listen, and respond dialectically to the limitations, geometries, and intrinsic potentials of the available matter. This approach brings in a poetic and narrative dimension into construction practice that reconnects the end user with the lifecycle of objects, promoting a new ecological awareness that relies not on deprivation, but on the creative abundance of the existing resource.

Deepening the relationship with Regenerative Design, upcycling appears as the essential strategy to overcome the narrow limits of traditional sustainability. Although conventional sustainable design is frequently oriented toward damage limitation, striving laboriously to reach a “zero impact” equilibrium point (which effectively is still a conservative objective), regenerative design aspires to produce an active, evolutionary, and positive impact on ecosystems.
According to the theoretical perspective outlined by Bill Reed (2007), regenerative design acts to restore and improve the health of living systems, transforming architecture from a resource-dissipative system into an active catalyst of value integrated into the biological and technical cycles of the biosphere.

Upcycling converges toward this direction through a fundamental methodological guideline: maintaining low entropy. While in traditional recycling matter is decomposed, melted, or shredded (operations requiring enormous energy flows and degrading structural quality), upcycling preserves the embodied energy and technical complexity previously paid for by the environment. Retaining the form and ennobled function of an architectural element means respecting the practices of care and labor already performed by human beings and nature, avoiding the re-emission of massive quantities of CO_2 in industrial remanufacturing processes.

In this perspective, the importance of upcycling resides in its ability to operationally implement the concept of the building as a “Materials Bank” (Materials Passports). If regenerative design intends to reconstruct natural capital, upcycling is the technical tool enabling the management of technical capital without further depleting the planet’s virgin resources. This approach demands a scalar leap: from the individual component to the urban system, transforming the perception of the existing building stock into a true “Urban Mining” reserve from which to draw, not to destroy, but to evolve matter into new states of order, complexity, and beauty.

Beyond technical-environmental aspects, upcycling promotes a new aesthetics of robustness and permanence. This poetics does not conceal the history or provenance of matter, but valorizes its marks, oxidations, fastening holes, and temporal stratifications, rendering time visible as an added construction material. Such material transparency serves a serious social and psychological function: it reconnects inhabitants to the vital processes of their spaces, educating them in the culture of care and frontally opposing the logic of bulimic consumption and throwaway replacement. An “upcycled” building component carries a dense story that invites maintenance and respect, core elements of a society intending to regenerate not merely the physical environment, but also the ethical and identity bond between people and built space. The aesthetics of upcycling is thus neither a formal caprice, a fad, nor an industrial style exercise, but the visible expression of an ethics of responsibility that transforms the physical “limit” of waste into a strategic resource for the survival of the architectural discipline.

Every architectural intervention adopting this logic does not limit itself to keeping the status quo, while actively contributes to the reconstruction of the territory’s natural and technical capital, demonstrating that upcycling is not only about the material’s past (where it comes from), but the system’s future (what it can generate), evolving the quality of the built environment toward a lasting, fruitful, and ultimately regenerative symbiosis with the biosphere.

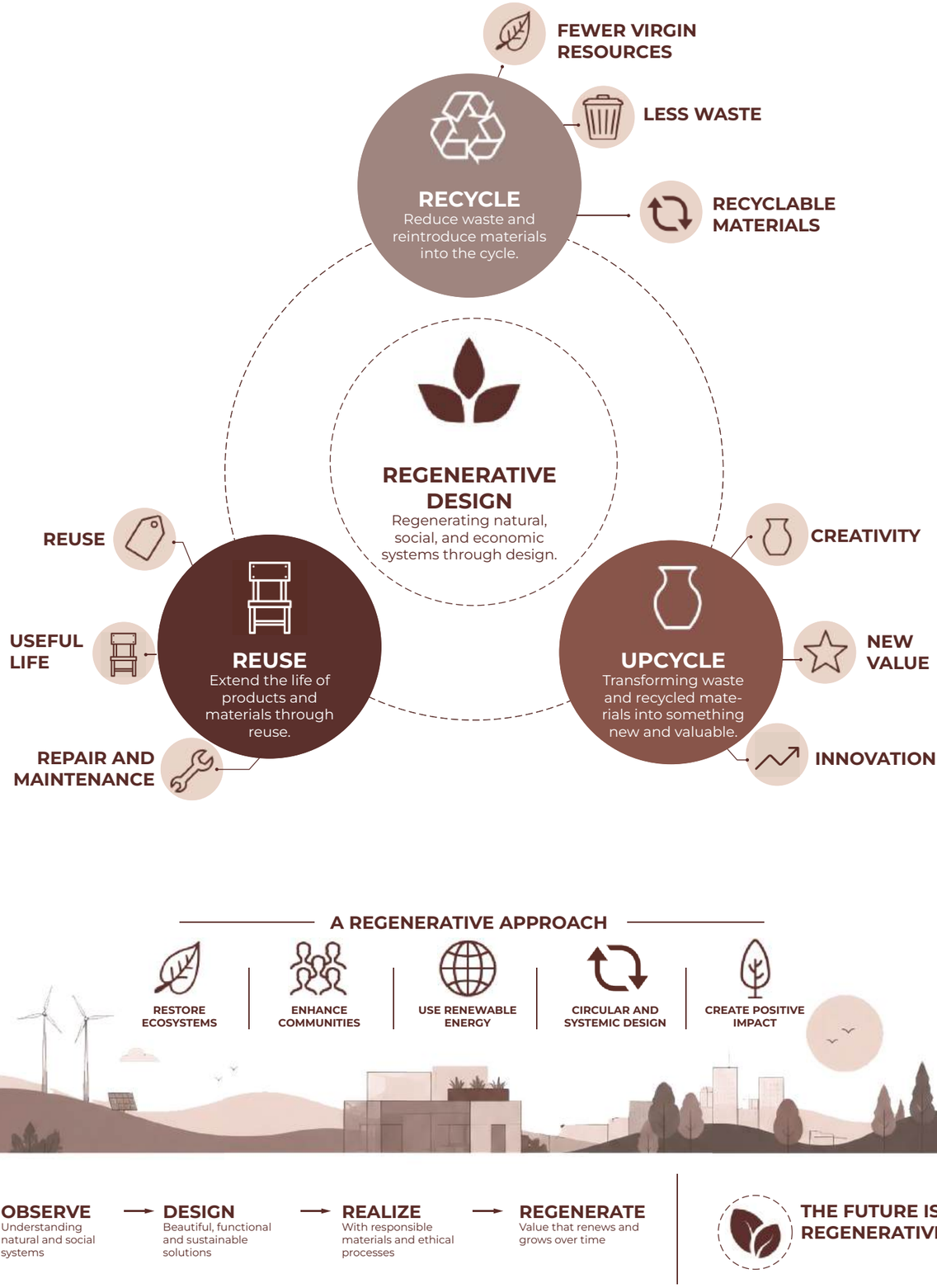


Fig. 8_ The regenerative approach and the differences between Recycle, Reuse and Upcycle. Source: *personal processing*



Fig. 9 _ Differences between Recycle, Reuse, and Upcycle. Source: *personal processing*

PARAMETER	RECYCLE	REUSE	UPCYCLING
Treatment of the Form	**Destruction:** The object is shredded, melted down, or reduced to secondary raw material.	**Conservation:** The object or building maintains its original morphology and function.	**Metamorphosis:** The original form is preserved but reinterpreted in a new configuration.
Post-Process Value	**Downcycling:** Loss of intrinsic quality and performance degradation.	**Unchanged:** The functional and performance value remains almost constant.	**Increased:** The scrap acquires a higher aesthetic and functional value than the original.
Energy Balance	**High:** Requires significant energy inputs for industrial transformation.	**Minimum:** Limited to energy for disassembly, transportation and maintenance.	**Low/Creative:** The main input is design intellect and light workmanship.
Building Example	Crushed concrete used as a road base.	Steel beams dismantled and reassembled in a new load-bearing structure.	Obsolete industrial components transformed into high-end façade systems.
Strategic Focus	**Waste management:** Reduction of volumes sent to landfill.	**Conservation:** Elimination of newly produced grey energy.	**Regeneration:** Recycling waste and creating new technical capital.

Fig. 10 _ Summary table on the differences between Recycle, Reuse, and Upcycle. Source: *personal processing*

Upcycling as an operational tool

Within this renewed regenerative perspective, the act of design undergoes a radical redefinition. While traditional sustainability has historically focused its efforts on improving active energy flows and the thermophysical performance of the building envelope (concentrating almost obsessively on containing the consumption of energy, water, and heat during the operational phase of the building), regenerative design executes a radical and essential shift in the axis of investigation toward the intrinsic quality, provenance, and permanence of matter.

Within such theoretical furrow lies the concept of the "**Material Capital**" of the existing built environment: a vision that recognizes in every single building component already put in place a stratified and irreplaceable deposit of embodied energy, specialized human labor, atmospheric emissions already produced, and collective historical memory. Indiscriminate demolition, from this perspective, does not simply represent a logistical inefficiency or a waste management problem to be directed to a landfill; it constitutes, more gravely, an irremediable destruction of energetic and intellectual capital that society has already laboriously invested in the built environment.

We must ask ourselves: *is every cubic meter of concrete, every steel profile, or timber module present in our cities not, in fact, a "loan" we have taken from the biosphere?*

If we accept this premise, dispersing such resources through demolition means betraying the value of that ecological debt already contracted, making the act of building a failing operation from the standpoint of the planetary balance. Material Capital suggests that matter is not a consumable good, but a patrimonial asset of the community.

Upcycling therefore appears as the operational and intellectual instrument of choice for the management and re-evaluation of this heritage. It breaks away sharply from conventional recycling practices which, while preferable to abandonment, frequently entail a phenomenon of downcycling: a process of degradation of the chemical-physical properties of materials that reduces their value and paradoxically requires further and massive energy inputs for their transformation into lower-quality products (consider structural concrete crushed to become simple road sub-base).

Upcycling, by contrast, does not aim at the passive conservation of residual value, but aspires to its qualitative elevation through design. Through the application of a renewed tectonic sensibility and refined recovery engineering, waste is reinterpreted to increase its structural performance, aesthetic dignity, and durability over time. Matter ceases to be an inert, anonymous, and standardized entity (subject to the laws of serial production) and becomes a resource dense with narrative and technical potential, whose "second life" can aspire to surpass, in complexity and fascination, the first function for which it was conceived.

Accepting the validity of material capital also means operating a necessary and urgent aesthetic and cultural reversal. The patina of time, the oxidation of metal surfaces, the imperfections of wood, or the traces of previous uses must no longer be interpreted as signs of obsolescence, degradation, or performance failure. On the contrary, they should be celebrated as tangible evidence of the resilience and history of matter. Designing starting from what exists imposes upon the architect a methodological challenge of an almost archaeological nature: it is not a matter of inventing forms ex nihilo, but of knowing how to decode the traces of the past to project them into a vision of a regenerated future.

In this sense, the quality of matter becomes the linchpin of an architecture that does not voraciously consume land and resources, but inhabits the world through evolutionary maintenance. The architect is elevated from the role of mere prescriber of industrial catalogs to that of orchestrator of vital cycles, capable of conferring an unprecedented dignity upon what the bulimic logics of the building market had prematurely condemned to oblivion. Upcycling, ultimately, becomes the bearer of an ethics of permanence that does not deny change, but governs it, guaranteeing that matter, once extracted and transformed, remains forever an active and noble part of the urban beauty production cycle.

The transition toward a regenerative model finds its theoretical and operational foundation in the overcoming of the "eco-efficiency strategy."

As theorized with force by William McDonough and Michael Braungart in the manifesto ***"Cradle to Cradle: Remaking the Way We Make Things"*** (2002), the objective of contemporary design must be to radically redesign the system itself so that every waste ceases to be a problematic residue and becomes a nutrient for a new cycle.

In this perspective, efficiency (understood as the reduction of flows within an extractive model) is seen as a partial and dangerous solution, since it limits itself to maximizing an intrinsically degenerative system. Transitioning to regenerative design implies, conversely, definitively abandoning the linear "extraction-production-waste" logic in favor of a symbiotic logic, where the building is no longer the terminal point of a consumption chain, but a temporary accumulator of resources destined for infinite rebirths.

This metamorphosis of thought shifts the center of gravity of architectural action: regenerative architecture no longer interrogates the biosphere asking "*what can I still extract?*", but stands before the existing building stock, understood as a "Material Bank," asking: "*what can I still become?*". Such a question is not purely rhetorical, but represents a methodological challenge that necessitates overcoming the concept of passive environmental protection (frequently reduced to preservation constraints or conservative restoration) to embrace that of active evolution.

In this scenario, design is no longer an act of imposing a form upon virgin matter, but a process of listening to the latent potentials in what already exists.

Adopting a symbiotic logic thus signifies acknowledging that the built environment possesses its own metabolism. If in the linear model the building exhausts itself with demolition, in the regenerative paradigm the building decomposes to nourish other urban organisms. Upcycling, in this context, transforms the construction site from a place of waste production to a place of regeneration, defining an architecture that does not subtract value from the biosphere and actively contributes to it, equating the act of building with that of cultivating.

Upcycling between ethics and aesthetics

The efficacy of upcycling within the complex and stratified urban metabolism cannot be measured exclusively through the lens of individual creativity or isolated architectural experimentation; ultimately, it depends on the systemic capacity to structure a proximity logistics that is coherent with the laws of thermodynamics and real environmental balances. There exists, in fact, an insurmountable physical and cinematic limit defining the sustainability of these practices: if, in order to intercept, ennoble, and reinstall a decommissioned component, we are forced to subject it to extended-distance transport processes or excessively energy-intensive industrial operations that profoundly alter its molecular nature, the overall environmental balance risks slipping into a paradoxical deficit. In this scenario, upcycling would fail its primary mission, producing a carbon footprint and resource outlay superior to those required for the ex novo production of standardized and pre-certified virgin matter.

Upcycling raises an aesthetic and ontological provocation that deeply interrogates the basic foundations of contemporary architectural language. The critical question that arises is:

“Are we genuinely ready, as a society and as designers, to accept a spatiality founded upon the necessary exposure of the fragment, the material scar, imperfection, and explicit temporal stratification?”

The language of upcycling breaks with the canons of polished perfection, timeless minimalist abstraction, and industrial homogeneity that have dominated Modernism and its late-contemporary derivations, where the building was expected to appear as an alien, immaculate object devoid of past and material debt. In this new regenerative paradigm, beauty no longer resides in the removal of the traces of age or in the denial of a material’s provenance, but in the demiurgic capacity of the design to **recompose the heterogeneous, the decommissioned, and the fragmentary** into a new, coherent unit dense with meaning.

Nevertheless, one must stay critical: upcycling runs the risk of being reduced to a mere operation of aesthetic greenwashing if a real transformation of production processes does not support it. . The challenge, therefore, is not simply technical, engineering-related, or regulatory, but exquisitely cultural and philosophical. Upcycling within urban metabolism must not and cannot be interpreted as a fallback solution, an emergency strategy dictated exclusively by material scarcity; on the contrary, it must be elevated to a **conscious, programmatic, and proud linguistic choice**. It is about transforming the physical limit of the existing (with all its fixed dimensions, inherited drillings, oxidations, and patinas) into a new form of resilient, narrative, and truly human beauty.

True urban regeneration thus requires a radical and courageous rethinking of contemporary production geographies through the creation of zero-kilometer “**upcycling districts**.” These new logistical and creative poles should act as active metabolic filters, situated strategically in close proximity to major waste production centers (such as selective demolition sites, industrial areas undergoing decommissioning, or municipal solid waste sorting nodes), allowing secondary raw material to be intercepted before it loses its intrinsic value and is irreversibly declassified to the status of undifferentiated waste.

Only through a capillary network of local transformation laboratories can the **urban mine** cease to be a theoretical abstraction or an intellectual whim and transform into an operational and economic infrastructure capable of feeding building cycles with already refined resources, drastically reducing the negative externalities linked to global freight movement and dependence on transnational extractive supply chains.

This aesthetic transition requires a radical change in the social and professional contract between the architect and matter: accepting the aesthetics of reuse means renouncing the claim to control over form to welcome a practice of critical assembly, negotiation with the unexpected, and erudite technological bricolage.

This poetics of reuse not only slashes environmental impact, but improves the urban landscape with stratified meanings, reconnecting the inhabitant with the lifecycle of the objects and spaces they inhabit. It builds a culture of maintenance, repair, and respect that represents the true keystone of any authentically regenerative society.

Ultimately, upcycling shifts the center of gravity of architecture from pure form to responsible matter, defining a new aesthetic canon where the **ethics of conservation and the aesthetics of transformation finally coincide in a single, powerful design and political gesture.** Only thus can architecture hope to overcome its current condition of a dissipative system to become, finally, an engine of bioscenic and social regeneration.





Left:
Fig. 8_Officina Roma - Francesco Apuzzo, Jan Liesegang, Roma, 2011. Source: *raumlabor.net*
Fig. 9_1000 Doors - Choi Jeong-Hwa, South Korea, 2011. Source: i*nhabitat.com - Mike Chino*



Right:
Fig. 10_Alp of Spring - Use Design, Shangai, 2023. Source: *hisheji.com*

1.3. Urban Mining: mapping the material stock

The discipline of Urban Mining, emerging forcefully within the debate on strong sustainability, radically overturns the geographical and geopolitical perspective of raw material procurement: the resource deposit is no longer to be sought exclusively in the remote depths of the Earth's crust or in pristine ecosystems destined for extractive destruction, but resides visibly upon the already anthropized surface of the planet.

The resources that future architecture requires have already been extracted, processed, and put in place. Urban Mining configures itself as a true material security strategy for the urban territory. In an era distinguished by the volatility of raw resource prices and the growing scarcity of critical resources, the ability to read the city as a surface mine becomes a fundamental act of resilience.

The building is no longer the endpoint of a consumption chain, but a phase of temporary storage within a perpetual cycle.

Mapping the stock thus means decoding the complexity of the anthropogenic mine, converting urban entropy into an ordered and cataloged potential of technical and biological nutrients, ready to be reinjected into the architectural production circuit through selective deconstruction practices and systemic upcycling. Only by this rigorous mapping can the city finally emancipate itself from its capacity as a bulimic consumer of external resources to become a self-sufficient basin of regeneration.



Fig. 11_ "*Urban Mining* "- Park Associati - Source: *parkassociati.com*

The city as an anthropogenic deposit

The urban material stock is nothing other than the overall, stratified, and geolocalized accumulation of natural resources extracted from the Earth's crust, processed through energy-intensive industrial processes, and placed within the anthropized fabric over the centuries. In this perspective, the built environment is a surface mine or anthropogenic deposit, where value resides in the critical mass of already transformed matter that occupies it.

However, contemporary Urban Mining introduces a factor of systemic criticality that profoundly differentiates it from traditional extractive activity: the material density per cubic meter of the city is neither homogeneous nor directly accessible or easily cataloged through standard methods.

Investigating the dynamics of urban extraction reveals a fundamental distinction between the absolute quantity of material and its value intensity. A modern metropolis is, in fact, an accumulation of metals, minerals, and polymers with a specific concentration often superior to that of virgin natural deposits. It is estimated, for example, that the concentration of copper or gold present in electronic waste and obsolete infrastructure in a business district is several orders of magnitude higher than that found in a ton of rock extracted from an open-pit mine (Hagelüken & Goldmann, 2011; Ciacci et al., 2019). Yet, whereas a conventional geological mine is mapped through core drilling, seismic analysis, and stratigraphic models that allow for the prediction of a vein's yield with relative precision, the urban mine requires what we might define as preventive and multidimensional industrial archaeology. Mapping the built stock means undertaking a scientific census of the incorporated critical mass, evaluating not only its volume, but above all its degree of purity and tectonic accessibility.

The crucial challenge that Urban Mining poses to the culture of design is the radical transition from passive building management (interpreted as an artifact that becomes waste only at the traumatic moment of demolition) to a**ctive and predictive management**. In this new scenario, every built volume must be treated as a dynamic mining asset, a physical capital whose chemical composition, mechanical resistance, and, above all, predisposition to disassembly are perfectly known. This implies an overturning of the concepts of property and duration: the building is no longer a consumer good that exhausts itself with use, but a temporary deposit of resources that society decides to immobilize for a certain period, with the awareness that such capital must be returned to the urban metabolic flow without qualitative losses.

An inescapable essential node nevertheless arises regarding informational entropy. Very often, the existing building heritage is a **mute mine**: we do not know with certainty the metal alloys in hidden pipes, the purity of polymers in 1990s window frames, or the presence of toxic additives and flame retardants in old thermal insulation. Mapping the material stock thus means engaging in a struggle against this loss of historical information. Without reliable retroactive technical documentation, Urban Mining risks producing contaminated materials that force downcycling rather than upcycling. Active management therefore requires the integration of advanced digital tools, such as Digital Twins and GIS (Geographic Information Systems), capable of simulating the behavior of the urban deposit over time and predicting with precision when a given area of the city will become "ripe" for material harvesting based on component obsolescence cycles.

From the standpoint of systemic critique, considering the city as an anthropogenic deposit imposes a severe revision of the expansive urban growth model. If the resource is already here, within the consolidated perimeter, traditional mining in remote territories (frequently associated with geostrategic conflicts and ecosystemic devastation) becomes not only ecologically criminal, but economically illogical. The material density of our metropolises represents a reserve of value that, if properly mapped and managed, could make the construction industry finally independent of fluctuations in virgin raw material markets.

The city, therefore, ceases to be a parasite of the biosphere draining resources from the exterior and transforms into an autotrophic organism, capable of feeding upon its own residues. But this transition requires an urban extractive technology that is non-destructive, but rather surgical: no longer the wrecking ball that shatters and mixes nutrients, rendering them unusable, but a process of selective deconstruction acting as precision extraction.

The true paradox plaguing the metabolism of contemporary cities, blocking their transition toward real circularity, lies in the extreme and entropic qualitative heterogeneity of the existing stock. Much of the built heritage, especially that dating from the post-WWII building boom and the subsequent era of massive industrial chemistry, is in fact an immense deposit of what William McDonough defines as "monstrous hybrids" (McDonough & Braungart, 2002).

These are technically sophisticated compounds that are biologically or technically incompatible, wherein technical nutrients have been fused, glued, additivated, or irreversibly stratified with biological nutrients.

In this scenario, mapping the urban stock does not simply mean taking inventory of warehouses, but performing a serious and necessary ontological separation of flows.

Urban Mining, to raise itself to a scientific practice and prevent being reduced to a masked form of demolition scrap management, must obsessively target the **isolation of pure nutrients**. The ultimate goal is the surgical decomposition of the complex artifact into its elementary units so they can be re-inserted into their respective cycles without any cross-contamination that would preclude upcycling or, worse, cause toxic decay.

An advanced, critical, and conscious mapping must therefore be capable of identifying not only the quantity of material present in a given district, but also its **reversibility coefficient** and its **residual purity grade.**

This analysis shifts attention from the material as an object to the material as a capability for transformation. The compelling need for analytical instrumentation that goes beyond fallacious visual inspection arises here: mapping the chemistry of urban flows today requires the employment of portable scanning techniques derived from the traditional mining industry, such as XRF spectroscopy or hyperspectral sensors, capable of reading through layers of paint and surface coatings to identify the real metallurgical or polymeric nature of hidden substrates.

However, the intrinsic limit of this information extraction lies in the opacity of past construction processes, frequently lacking documentation regarding the composition of binders or additives. It is precisely within this cognitive-based gap that the concept of the Material Passport appears as the operational tool par excellence. By scrupulously documenting the component's history, the passport certifies its healthiness, the maintenance cycles it has undergone, the structural loads it has sustained, and, a fundamental parameter for the urban mine of the future, its intrinsic predisposition to detachment (Design for Disassembly). Without this widespread informational infrastructure, Urban Mining is still a blind, uneconomic, and potentially dangerous operation.
This approach not only minimizes the energy required for mechanical separation, but also maximizes the permanence of the structural, economic, and semantic value of the built heritage, rendering the city a dynamic archive of inexhaustible resources.

Limits and potential of Urban Mining

Despite the immense theoretical potential and the fascination surrounding the concept of the circular economy applied to the urban scale, Urban Mining must today confront a ruthless systemic critique, rooted not only in market fluctuations but in the inescapable laws of physics and thermodynamics.

The core issue of this discipline, and its greatest operational limit, is represented by **entropic dispersion:** the idea that not everything technically mapped, localized, and censused within the built stock is actually recoverable with a real ecological, energetic, or social profit. There exists, in fact, a critical entropy threshold, a thermodynamic point of no return beyond which the effort (expressed in terms of Joules, person-hours, and kilometers traveled) necessary to separate, purify, and ennoble a material dispersed within a complex architectural artifact requires a principal energy expenditure superior to that required for virgin mining extraction. If, in order to recover a few kilograms of a noble metal or a technical polymer from a composite panel, we consume a quantity of resources that neutralizes the emissions savings, Urban Mining betrays its mission, transforming itself into an exercise devoid of regenerative substance.

This criticality emerges with brutal evidence when we critically examine the architecture of the last seventy years, an era distinguished by a material promiscuity without historical precedent. The massive use of cyanoacrylate structural glues, polyurethane insulating foams expanded directly into cavities, plasters reinforced with synthetic fiber meshes, and glued multilayer clippings render the city a dirty mine, with low yield and an intrinsically difficult-to-cultivate nature. In these cases, the material is imprisoned in a molecular configuration that opposes extreme physical resistance to disassembly.

Mapping the stock in these contexts is an act of intellectual honesty that frequently leads to a bitter conclusion: much of our current built environment, while being a theoretical reserve of nutrients, actually represents a colossal entropic debt which future generations will struggle to extinguish, since the cost of material decontamination will exceed the value of reuse.

The true challenge of the next decade, therefore, no longer resides solely in the archaeological mapping of the existing (however necessary to avoid the definitive collapse of material flows) but in a radical and courageous redesign of the new so that it is, by ontological statute, easily extractable. The Urban Mining of the future cannot merely be a posteriori extractive activity, a sort of tardive remedy for past design errors, but must configure itself as an action of speculative and preventative design.

This paradigm shift is founded upon the **total reversibility of connections**: if today we design and map components conceived according to the exact protocols of Design for Disassembly (DfD), we are not only constructing a building, but we are operating a long-term infrastructural investment for the stability of the urban metabolism. Assuring the separability of every joint, the chemical purity of every nutrient, and the visibility of every material passport means handing over to tomorrow's designers an urban mine with high yield, low energy intensity, and very high added value.

We must nevertheless rigorously ask ourselves:

Are we genuinely ready to renounce the economic and performance convenience of irreversible construction solutions (which guarantee rapid installation but absolute impossibility of recovery) in the name of an intergenerational thermodynamic responsibility?

The aesthetics of reversibility, with its exposed bolts, dry joints, legible stratifications, and construction honesty, openly challenges current tastes for monolithic, sculptural, and jointless architecture.



Fig. 12_ *A Guide to Design for Disassembly* - Assessing materials. Source: *archdaily.com*



Fig. 13_ *A Guide to Design for Disassembly*- Choosing connection details. Source: *archdaily.com*

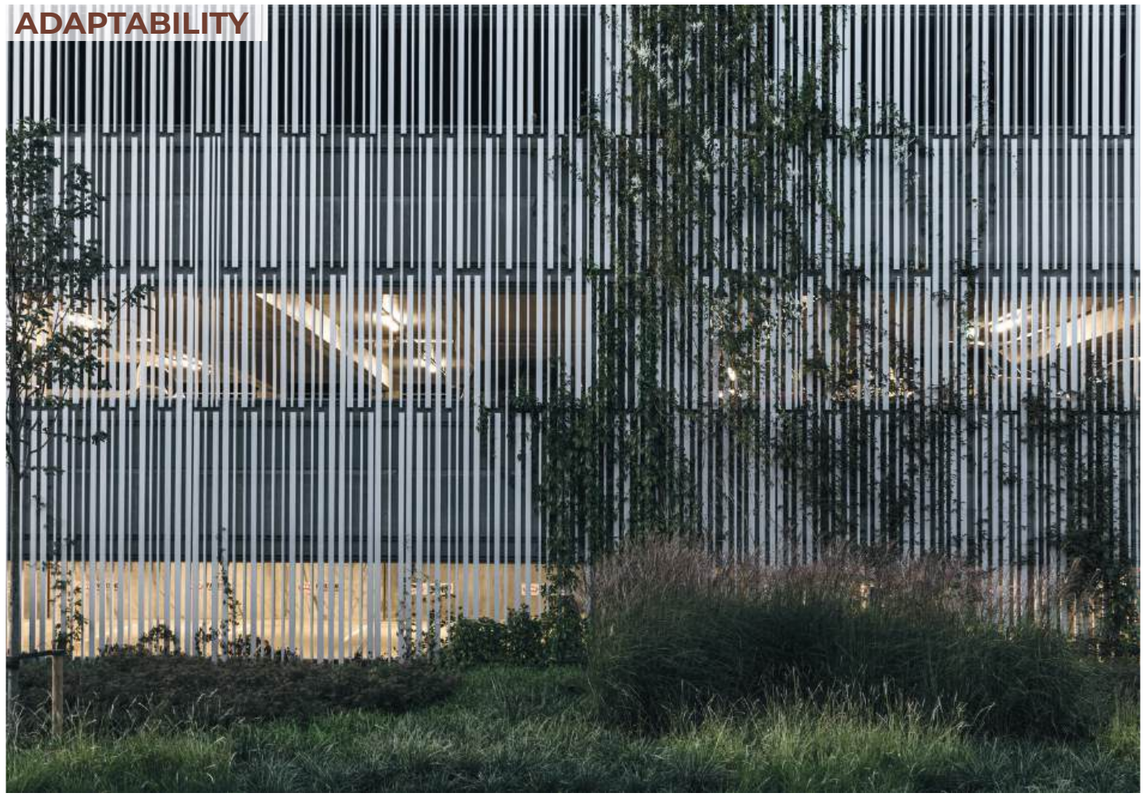


Fig. 14_ *A Guide to Design for Disassembly* - Designing for Adaptability. Source: *archdaily.com*

Design for Disassembly (DfD)

Urban Mining, understood as the operational and philosophical paradigm of urban metabolism, imposes a radical, almost violent revision of conventional building end-of-life techniques. Traditional demolition, based on indiscriminate destruction via devastating mechanical impacts and subsequent, often approximate separation of debris on the ground, represents today the most inefficient and thermodynamically dissipative form of urban mining exploitation. This approach generates what literature defines as "**construction site entropy**": by mixing heterogeneous materials in a disorderly mass (from gypsum to reinforced concrete, from treated wood to complex polymers), it inevitably degrades the intrinsic quality of nutrients, condemning the matter to downcycling (such as inert crushed stone for road sub-bases) or, in the worst case, to the toxic oblivion of the landfill.

In direct antithesis to this dissipative practice, the scientific mapping of material stock guides and legitimizes **selective deconstruction** (or disassembly). This is a surgical, slow, reasoned, and conscious process that rigorously inverts the phases of original assembly. If the material map indicates, with millimetric precision, the presence of high-quality technical nutrients (such as extruded anodized aluminum profiles, low-alloy structural steel beams, flat glass panes, or complex copper and rare earth systems), urban mining ceases to be an act of brute force and configures itself as systematic dismantling. The main objective is no longer the disposal of bulky volume, but the absolute preservation of the official and functional integrity of the individual component. In this context, the building is no longer demolished in a cataclysmic and dusty event, but is dismantled layer by layer, piece by piece, respecting the tectonic hierarchy of construction elements as if it were an operation of reverse restoration.

However, a critical analysis cannot avoid highlighting the enormous systemic resistances this model encounters. Selective deconstruction requires significantly longer execution times and the employment of highly specialized labor, transforming the construction site from a place of anonymous destruction into a laboratory of future archaeology.

From a short-term economic standpoint, the labor cost of carefully dismantling a window frame or a bolted connection often exceeds the market value of the equivalent virgin material, owing to a tax system that heavily taxes labor and almost nothing on primary resource extraction. Yet, if we shift the analysis to the global energy balance and environmental externalities, it emerges that the massive savings in embodied energy widely compensate the additional effort of deconstruction. Returning intact elements to the material bank, ready for upcycling and equipped with a digital passport, means zeroing out the environmental impact linked to primary refining, very high-temperature melting processes, and the transoceanic transport of virgin raw materials often extracted in contexts of geopolitical exploitation.

Furthermore, selective deconstruction acts as a ruthless reality test for contemporary architecture: it lays bare the intrinsic unsustainability of those construction solutions that use cyanoacrylate glues, expanding polyurethane foams, and irreversible chemical couplings that physically prevent the separation of nutrients.
Effective urban mining thus requires, as an ethical and technical precondition, a "Design for Disassembly," wherein every connection (bolt, interlocking joint, screw, dry joint) is conceived to be unscrewed rather than broken, honoring the reversibility of the constructive gesture.

Ultimately, the transition from destructive extraction to selective deconstruction marks the evolution of the construction sector from an extractive model of pillage to a model of maintenance and care of earthly flows.

The deconstructed building ceases to be a pile of rubble to be concealed, becoming instead a strategic reserve of value that is not dispersed, but rather redistributed capillarity throughout the urban fabric. This procedure guarantees that the ingenuity, labor, and energy invested by past generations remain an active, noble, and usable resource for tomorrow's architectural necessities, transforming the end-of-life of an artifact into the incipit of a new, conscious tectonic narrative. Only through this **surgery of the built environment** can the city hope to emancipate itself from its bulimic dependence on external resources, becoming an ecosystem capable of self-regeneration without producing waste.



Fig. 15_ Wooden Nursery - Djuric Tardio Architectes, Paris, 2020. Source: *A Guide to Design for Disassembly, archdaily.com - Clément Guillaume*

Material-Led Design

If classic linear architecture follows a unidirectional and dissipative flow following the post-industrial paradigm of take-make-waste9 the consistent integration of upcycling into the urban metabolism provides an intentional, political, and thermodynamic distortion of this trajectory.

Within that regenerative horizon, resources no longer progress toward the simplification and qualitative degradation typical of refuse; rather, they are intercepted and redirected toward new states of order, functional complexity, and informational density.
In this scenario, the critical question that design must ask itself shifts from the bureaucratic logistics of volume management ("*how can we conceal or dispose of waste?*") toward a serious ontological and performance-oriented inquiry:

"What new form of life, what semantic surplus, and what tectonic dignity can this subject claim in its next cycle of use?"

This interrogation moves the axis of value from the material as an anonymous substance to the material as an artifact of prior intelligence, forcing the designer to confront the physical heritage of the built environment not as a liability, but as a deposit of opportunity.

Upcycling openly challenges massive industrial standardization, which tends to homogenize resources to make them easily processable by a production machine that tolerates neither the unexpected nor singularity. Conversely, it requires a phenomenological, almost archaeological sensitivity when observing decommissioned components: they must be perceived as geometries endowed with technical memory and specific material identity, awaiting preservation and enhancement. An oxidized steel beam, a glass panel removed from an obsolete envelope, or a mechanical production byproduct are not system errors to be corrected, but bearers of layered mechanical performance and aesthetic qualities that can be reactivated through a conscious design act.

This approach imposes a radical inversion of egocentric creative processes. While in the conventional model the architect acts as a demiurge, imposing an ideal, abstract form onto virgin matter, treated as uncritical, mute, and infinitely malleable, in upcycling, the concept no longer comes from the void of the blank page. Instead, it models itself dialectically upon the tectonic potentials and physical limits of available waste. We thus witness the transition from **top-down design** to a **material-led practice**, where constraints (fixed dimensions, existing anchor holes, temporal patinas, and traces of past uses) are no longer interpreted as penalizing limits, but as generative inputs guiding non-arbitrary linguistic innovation.

For upcycling to effectively accomplish the necessary scalar leap (transitioning from the dimension of isolated experimentation (often confined to art installations, furniture, or temporary pavilions) to the macroscopic, complex, and systemic scale of the urban metabolism) the very structure of building production and the construction supply chain must be radically reorganized. This metamorphosis requires the adoption of a strict theoretical and working framework, identifiable in the principles of the Cradle to Cradle paradigm.

Developed in the late 1990s by architect William McDonough and chemist Michael Braungart, this approach goes beyond the linear logic of waste management to impose a true ontological taxonomy of matter, founded upon the post-use destination of flows and the earliest chemical purity of components. Cradle to Cradle rejects the very idea of "waste," theorizing that every material must be designed as a nutrient destined to flow perpetually within two independent, well-defined circuits: **the biological metabolism** and the **technical metabolism.**

The Biological Metabolism

Governs all materials and products deriving directly from the biosphere, consisting of stable organic compounds that, at the end of their use, can be reintegrated into natural processes without altering ecological or biochemical balance. Within a regenerative urban vision, upcycling applied to this specific category assumes an agricultural, industrial, and symbiotic connotation simultaneously. It is not limited to simple composting; rather, it consists of systematically intercepting waste flows from collateral sectors (such as agro-industrial food byproducts, forestry residues, natural waste textile fibers, or organic residues from public green space maintenance) to subject them to chemical and biotechnological upcycling. Through the application of green chemistry and advanced biotechnologies, these waste biomasses are ennobled and transformed into high-performance technological compounds and construction components, overturning the stereotype associating natural materials with poor, fragile, or structurally limited solutions.

The authentically regenerative challenge characterizing the biological cycle lies in the rigorous preservation of total non-toxicity and the perfect biodegradability of the final element. At the end of their functional cycle, these components generate no environmental load, converting instead into true soil conditioners and nutrients for urban and suburban soils, closing a perfect metabolic loop where the end of the architectural artifact coincides with the ecological regeneration of the territory.

The Technical Metabolism

Manages synthetic, artificial, and mineral nutrients (such as metals, petrochemical-derived polymers, high-tensile alloys, and ceramic compounds), meaning all materials that cannot be absorbed or digested by the biosphere without provoking irreparable damage or toxic bioaccumulation phenomena present in living ecosystems. In this scenario, upcycling responds to completely different criteria, focusing on the extreme conservation of geometric form, structural strength, and, above all, the embodied energy contained within the component in its current state.

Practicing technical upcycling in the construction sector means firmly opposing the conventional industrial practice of undifferentiated recycling or mass demolition. The cornerstone concept is maintaining the systematic and functional complexity of the object.

The ultimate objective of upcycling technical nutrients is therefore not the fragmentation of matter to recover its original atoms or molecules, but the reuse of the constructive and functional intelligence already enclosed within the artifact. Anthropogenic materials are thus preserved and valorized within closed, controlled industrial circuits operating on an uninterrupted cycle, configuring themselves as true material banks or digital materials passports. Within those logistical and informational infrastructures, technical components are cataloged and ready to be installed, disassembled, and subsequently reassembled in infinite future spatial and structural configurations, never touching the ground as waste and never dispersing the intrinsic, economic, and thermodynamic value conferred upon them by human labor and original energy.

The “Material Bank” and the traceability paradox

The concept of Material-Led Design shifts the perception of the building from a static, terminal artifact destined for inevitable decline to a temporary repository of material capital with high energetic and functional potential. In this new vision, architectural work ceases to be an endpoint of the production process and becomes a transit node within a continuous circular flow. If we accept upcycling as the beating engine of urban metabolism, we must nevertheless confront the **paradox of traceability:** a technical, regulatory, and philosophical challenge that threatens to hinder the transition toward real systemic regeneration.

The fundamental question that arises, and which puts current construction practice into crisis, is how it is possible to guarantee the structural safety, chemical health, and thermophysical performance of a recovered component if its so-called historical memory has been lost during decades of operation. Today’s construction industry is an intrinsically rigid system, founded on the millimetric performance certainty guaranteed by factory certifications, CE markings, and laboratory tests performed on virgin materials extracted and produced in controlled and standardized environmental conditions. Conversely, urban waste is by its very nature an anonymous and mute material. In the absence of a documented and unassailable pedigree, the upcycled material almost inevitably undergoes precautionary downgrading by control bodies and inspectors, a process that paradoxically condemns it to low-quality recycling (downcycling) or directly to the landfill, nullifying the entire creative, design, and sustainability effort that motivated the recovery attempt.

To solve this problem and allow matter to regain value, regenerative urban metabolism requires establishing a complex and rigorous value bureaucracy, based on the instrument of **Materials Passports.** This digital data infrastructure, ideally integrated into latest-generation Building Information Modeling (BIM) models, makes it possible to track geographical origin, granular chemical composition (essential to avoid the circulation of toxic substances banned over time), and the residual performance of every single component, descending almost to the atomic scale of the installed matter. Without this capillary informational framework, architectural upcycling remains restricted to the realm of artistic craftsmanship, ephemeral installation, or experimental self-construction, areas where structural safety and centurial durability requirements are less stringent than at the urban scale. The material passport transforms the building into a dynamic, transparent, and queryable archive, drastically reducing the informational entropy of the built system and allowing each element to be cataloged not only for the function it performs in the present, but for the regenerative potential it can express in the future.

However, the massive implementation of this model raises criticisms and systemic problems of no small account, which must be analyzed with a critical spirit. While on one hand the economic valorization of tracked waste allows transforming the traditionally passive costs of demolition into net revenues deriving from recovery and resale, on the other hand the enormous problem of so-called **Legacy Materials** arises. This refers to the immense existing building stock, constructed in pre-digital eras, which constitutes almost the entirety of our cities and is devoid of any reliable technical documentation on material constitution. Retroactively charting these volumes requires very high costs in terms of in situ investigations, laborious non-destructive testing, and laboratory chemical analyses, often making upcycling economically less competitive and riskier than purchasing virgin raw materials guaranteed by the global market.

Furthermore, a true regulatory abyss opens up regarding **legal and civil liability:** *in the event of failure or malfunction of an upcycled component after twenty years of renewed service, upon whom would the blame fall? On the first manufacturer who fabricated the piece fifty years earlier, on the designer who reinterpreted its use in a different structural context, or on the certification body that endorsed its residual performance based on digital data?* This legal uncertainty represents today one of the primary causes holding back the diffusion of upcycling on an industrial scale.

There is also the concrete risk of the **technical obsolescence** of the data itself: the digital technologies and file formats we use today could become unreadable or incompatible in fifty years, creating a new type of mute matter (this time digital) and rendering passports inaccessible precisely at the critical moment when the building should be disassembled.

Although these shadows and the technological difficulties remain open, the arguments in favor remain decisive for the construction of real urban resilience inside the century of resource scarcity. The availability of certain and accessible data allows optimizing industrial symbiosis flows at the territorial scale, enabling public administrations and private consortia to predict with extreme chronological precision when and which resources will become available on the market thanks to scheduled decommissioning. The regenerative building, conceived as a material bank, must therefore be designed from the outset according to the criteria of **Design for Disassembly (DfD)**, namely, design for facilitated disassembly, transforming the end of a structure’s use contract into a moment of systematic and orderly material harvesting.

In this perspective, the beauty of architecture no longer resides solely in its spatial plastics, but in the **ethical and technical transparency of its entire lifecycle**.

The **digitization of matter** thus becomes the political and technical tool to raise upcycling from a simple creative or decorative expedient to a certified and safe tectonic practice. This guarantees that future generations receive from our actions not an unquenchable environmental, energetic, and informational debt in the form of undifferentiated rubble, but a patrimony of precious resources, already refined and ready for use in new cycles of civilization. Only through the collective overcoming of the traceability paradox can architecture successfully cease to be a dissipative system of global capitals and finally transform into an agent of durable, equitable value in deep symbiosis with the cycles of the biosphere.

02

CHAPTER TWO

The European Regulatory Framework for the Circular Economy in construction

2.1. From EU Policies to flow Management

Upcycling and urban regeneration practices in architecture should not be viewed solely as aesthetic trends or isolated design decisions. Instead, they constitute an operational response to a fundamental shift in the legislative and political framework of the European Union.

In recent years, the European Union has undertaken a comprehensive revision of its growth strategies. Sustainability and circularity are now positioned as central pillars of a new model of industrial and environmental sovereignty, rather than as secondary objectives.

This chapter outlines the regulatory framework that is transforming the construction sector into an ecosystem focused on value preservation and climate neutrality.

The political foundation for the transition to an environmentally sustainable built environment is established by the European Green Deal, which commits member states to achieving net-zero greenhouse gas emissions by 2050. Within this framework, the construction sector is identified as a priority for intervention in both the New Circular Economy Action Plan (CEAP) and the “Renovation Wave” strategy. The “Renovation Wave” specifically redirects attention from new construction to the adaptive management of existing building stock, promoting recovery and upcycling as essential strategies for reducing embodied carbon in materials.

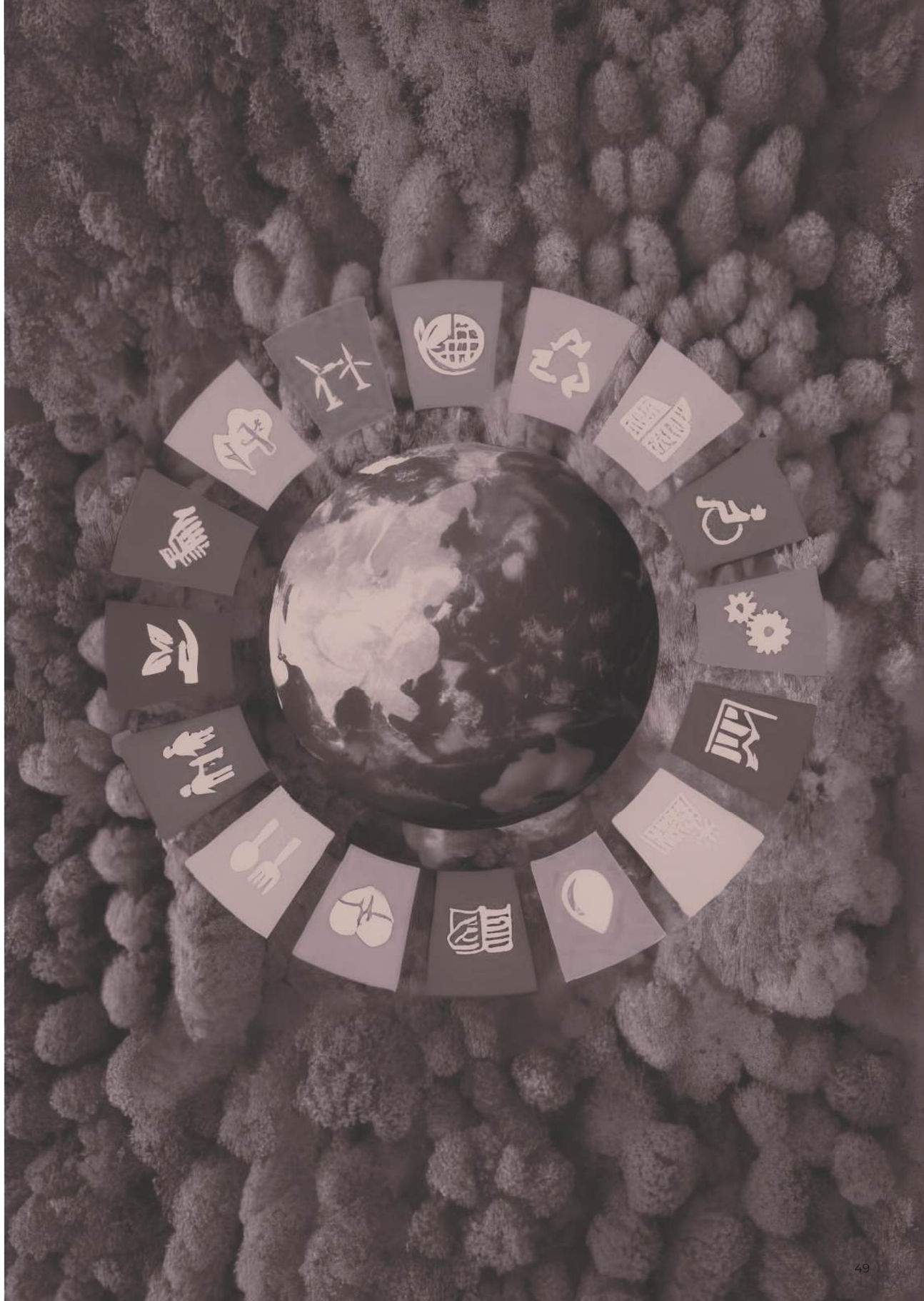


Fig. 16_ International Green Policies: From the 2030 Agenda to the European Green Deal. Source: *simbolia.net*

The European Green Deal and the “Zero Emissions” objective by 2050

The European Green Deal, presented by the European Commission in December 2019, is not simply an environmentalist declaration of intent; rather, it presents itself as the most profound macroeconomic and industrial transformation strategy ever undertaken by the Union.

Its crucial objective is to make Europe the first climate-neutral continent by 2050, a milestone that is not simply a political ambition, but a legal obligation enshrined in the European Climate Law. This climate neutrality, frequently defined as the **“Net-Zero” target**, requires a perfect balance between greenhouse gas emissions generated by human activities and the absorption capacity of the biosphere or technological systems. In this scenario, architecture and the construction sector are no longer considered passive actors, but become the operational fulcrum of the transition. The figures justifying this central role are monumental: the building sector is responsible for approximately 40% of final energy consumption and 36% of greenhouse gas emissions in the EU, while absorbing around half of all extracted raw materials and generating over one-third of the total mass of waste produced in Europe (European Commission, 2020).

The Green Deal consequently shifts the paradigm of architectural sustainability from operational efficiency (namely, how much energy a building consumes during its useful life) to the sustainability of the global lifecycle. This change of perspective is fundamental: whereas until recently the main goal was limiting the energy consumption of boilers and air conditioners, European legislation now recognizes that a large portion of a building’s environmental footprint is already “frozen” the moment the construction site opens (Embodied Carbon). To comply with the **“Fit for 55”** legislative package, which requires a 55% reduction in emissions by 2030, Europe promotes the **“Renovation Wave”** strategy. This plan intends to double the annual rate of energy retrofitting of the existing building stock, incentivizing practices that avoid demolition and reconstruction ex novo, processes that would entail an unsustainable expenditure of resources and new factory emissions tied to energy-intensive materials such as cement or steel.

In this context, climate neutrality by 2050 radically transforms the ethics of architectural design. Upcycling architecture fits perfectly into this regulatory trajectory, since it extends the useful life of pre-existing components, transforming the end-of-life of an artifact into the beginning of a new, high-value-added production cycle.

The European strategy thus intends to dismantle the linear economic model (based on extraction, production, and disposal) in favor of a circular model where preserving material value becomes the primary tool for decarbonization. Ultimately, the Green Deal asks for not only more energy-performant buildings, but a new culture of construction that views the existing building stock and its waste not as a bureaucratic burden to be managed, but as a strategic reserve of resources indispensable for remaining within the planet’s biophysical limits and achieving the challenging targets of climate neutrality.

The New Action Plan for the Circular Economy (CEAP)

The New Circular Economy Action Plan (CEAP), adopted by the European Commission in March 2020 as a key element of the Green Deal (final 98), marks the fundamental transition from waste management toward resource management.

While previous directives focused on the final phase of the product lifecycle, the CEAP intervenes upstream, acting upon design and production. Within this document, the built environment is explicitly designated as one of the key sectors (alongside electronics, batteries, and textiles) due to its devastating impact in terms of virgin raw material harvesting and waste generation. The Plan recognizes that the transition to climate neutrality is impossible without a structural reform of the construction sector, which currently represents approximately 35% of the total waste generation taking place within the Union.

The assimilation of the building sector among the CEAP priorities led to the definition of a specific **“Strategy for a Sustainable Built Environment.”** This document reinforces the need to promote circularity principles along the entire lifecycle of buildings, introducing requirements for spatial **flexibility** and **pliability**. For upcycling architecture, this represents unprecedented regulatory legitimation: the Plan does not simply encourage material recycling (which frequently results in downcycling processes, namely the degradation of matter into lower-value products such as road aggregates), but strongly promotes the preservation of the functional and performance value of components. In this sense, the document indirectly invokes the principles of **“Design for Disassembly”** and **constructive reversibility**, transforming the building from a monolithic block into a Material Bank.

A fundamental part of the CEAP concerns the harmonization of measurement criteria. Through the Action Plan, the European Commission promoted the use of the **Level(s) framework**, a reporting system aimed at measuring the sustainability performance of buildings through common indicators. Among these, the indicator concerning “Material Life Cycle and Resource Efficiency” assumes particular prominence, prompting designers to evaluate not only the origin of materials, but also their capacity for future reuse. This connects closely with the revision of the Construction Products Regulation (CPR), cited in the CEAP as a tool to facilitate the market placement of recovered and upcycled products, while guaranteeing safeguarding and transparency through the digitalization of information.

The CEAP also addresses the dimension of informational transparency. The document introduces the objective of creating **Digital Product Passports** and Digital Building Logbooks, which are key tools for Urban Mining. Without technical documentation attesting to the composition and quality of materials present in existing buildings, upcycling often remains an artisanal and complex practice. The CEAP intends to bridge this informational gap, advancing recovery a scalable and industrializable practice. Furthermore, the Action Plan exerts vigorous market pressure through Green Public Procurement (GPP), namely environmental criteria in public tenders. By imposing minimum quotas of recycled or reused materials in public works, the EU creates a stable market demand that incentivizes companies to invest in upcycling supply chains.

Ultimately, the New Circular Economy Action Plan transforms architecture into a discipline of strategic natural capital management. As highlighted in the document “Circular Economy – Principles for Building Design” (2020), published by the Commission as an operational extension of the CEAP, the objective is no longer merely to construct efficient buildings, but to create building systems able to self-regenerate.

The “Renovation Wave”

The “Renovation Wave” strategy, formalized by the European Commission in October 2020 through communication COM(2020) 662, serves as the operational and tactical component of the Green Deal as applied to the complexities of the existing building stock.

While the Circular Economy Action Plan defines the theoretical foundations of circularity, the Renovation Wave establishes both the urgency and scale of intervention, setting the ambitious objective of doubling the annual rate of energy renovations in buildings by 2030.
This initiative is driven by a significant empirical observation: approximately 85% of buildings currently standing in the European Union will remain in use by 2050, yet most exhibit outdated energy performance and high carbon emissions. The strategy extends beyond improving thermal efficiency through additional insulation; it introduces a systemic approach, termed the **“Strategy for a Sustainable Built Environment,”** which seeks to reconfigure the entire construction supply chain from a regenerative standpoint.

The principal paradigm shift introduced by this document is the adoption of **“Life-Cycle Thinking”** as a guiding criterion for all recovery interventions. The European Commission emphasizes that renovations focused solely on operational energy savings, while disregarding the environmental impact of construction materials, risk generating an initial carbon debt that is challenging to offset in the short term.

Within this regulatory context, upcycling architecture gains robust technical justification: the Renovation Wave explicitly incentivizes the use of circular materials and the preservation of the value inherent in existing built resources. Rather than adhering to the traditional approach of complete demolition, the strategy encourages viewing existing buildings as repositories of secondary raw materials, already processed and suitable for enhancement through new architectural functions.

From a technical standpoint, the strategy advocates for the implementation of digital asset management tools, such as “Digital Building Logbooks” and “Renovation Passports.” These registers function as dynamic instruments designed to map the urban resource base in real time, rather than serving as mere bureaucratic records. For practitioners employing upcycling principles, access to reliable data on the chemical and physical composition, mechanical resistance, and maintenance history of building components is essential to transition recovery from an artisanal activity to a scalable industrial process. Consequently, the Renovation Wave establishes the foundation for a market of certified “second-hand matter”, addressing performance uncertainties that have previously impeded large-scale reuse.

Additionally, the strategy is closely connected to the **New European Bauhaus (NEB)** initiative, which functions as the cultural and creative core of the Renovation Wave. The NEB encourages the design community to integrate technical performance with aesthetic quality and social inclusion, thereby advancing the valorization of waste materials. Within the New European Bauhaus framework, upcycling is redefined as an innovative expressive language that conveys the memory of a place through the reinterpretation of existing components, rather than serving as a secondary solution. This methodology enables simultaneous responses to the climate crisis and the erosion of urban identity, fostering “urban acupuncture” interventions in which the recovery of a single architectural element can catalyze broader social regeneration.

Finally, the Strategy for a Sustainable Built Environment leverages economic mechanisms through the multiannual financial framework and the **NextGenerationEU** program. The allocation of funds is increasingly contingent upon adherence to the **“Do No Significant Harm” (DNSH)** principle, which mandates that each financed project must not compromise the Union’s environmental objectives, including the transition to a circular economy.
This requirement necessitates that construction waste management aligns with recovery-oriented practices.

As a result, the Renovation Wave positions Europe as a large-scale experimental construction site, where adaptive maintenance and typological flexibility become standard practices.

In summary, upcycling is now positioned not merely as an act of ecological resistance, but as the cornerstone of a new industrial policy that regards the regeneration of existing structures as the only viable path to achieving climate neutrality by 2050 without exhausting the planet’s limited resources.







Fig. 17_Logos of the strategies implemented during the “Renovation Wave.” Source: *commission.europa.eu*

The Waste Framework Directive (2008/98/EC)

The Waste Framework Directive (2008/98/EC), consolidated and updated by the 2018 **Circular Economy Package** (European Commission, 2018), is not simply an environmental legislative act, but represents the political and technical manifesto upon which the entire transition toward sustainability within the European Union rests . Its most revolutionary contribution is the establishment of the waste hierarchy as a legally binding order of priority in legislation and material flow management policy. This five-tier hierarchical scale subverts the linear logic of the twentieth century, imposing a vision wherein landfilling is no longer the natural outcome of a product's lifecycle, but rather the failure of the production system itself.

At the absolute apex of the pyramid lies **Prevention**. In the building sector, this level does not pertain to managing what is already waste, but rather to the strategic planning of what must not become it. Prevention entails adopting an eco-design approach, reducing material intensity in construction, extending the useful life of buildings using spatial flexibility, and limiting waste generation during the construction phase. Prevention is the sole phase in the hierarchy that intervenes before a material can be classified as waste, acting directly upon the demand for raw resources and process efficiency.

Immediately below lies **Preparation for Re-use**. This is a fundamental technical distinction introduced by the Directive: unlike recycling, re-use allows for the preservation of the added value, form, and performance of the existing component. For the construction sector, this implies the development of a second-hand supply chain for elements such as structural steel beams, window frames, panels, or MEP systems which, following verification, cleaning, or repair, can be reintegrated into new works. The environmental value here is maximal, as it avoids not only disposal, but also the energy required to reprocess raw matter (namely, embodied carbon).

The third tier, **Recycling**, intervenes when the integrity of the component cannot be preserved. The Directive defines recycling as any recovery operation by which waste materials are reprocessed into products, materials, or substances. Within the context of construction and demolition (C&D) waste, the challenge posed by the Directive is to promote high-quality recycling while countering the phenomenon of downcycling. A critical example is aggregate recovery: the hierarchy pushes for crushed concrete to avoid ending up merely as sub-base fill for roads, and instead re-enter the production cycle of new structural concrete, effectively closing the loop of matter.

Other **recovery,** such as energy recovery, occupies the penultimate position. Although preferable to landfilling, it nonetheless represents a definitive loss of matter, which is destroyed to extract heat or electricity.

Finally, at the base of the hierarchy, we find **Disposal (**landfilling), which is regarded as a residual option to be disincentivized through fiscal levers and regulatory prohibitions.

The impact of Directive 2008/98/EC upon construction practice is significant: it compels Member States to fulfill ambitious quantitative targets (such as the 70% recovery target for C&D waste) and introduces the concept of **Extended Producer Responsibility (EPR).** This latter principle is destined to transform the relationship between material manufacturers and the market, obligating them to bear the responsibility for managing their products at end-of-life. Ultimately, the recovery hierarchy is not simply an operational guide for waste management, but a model of flow engineering that shifts the axis of value from the ownership of matter to the management of its function, assuring that every gram of extracted resource is maintained within the economic system at the highest possible performance level.

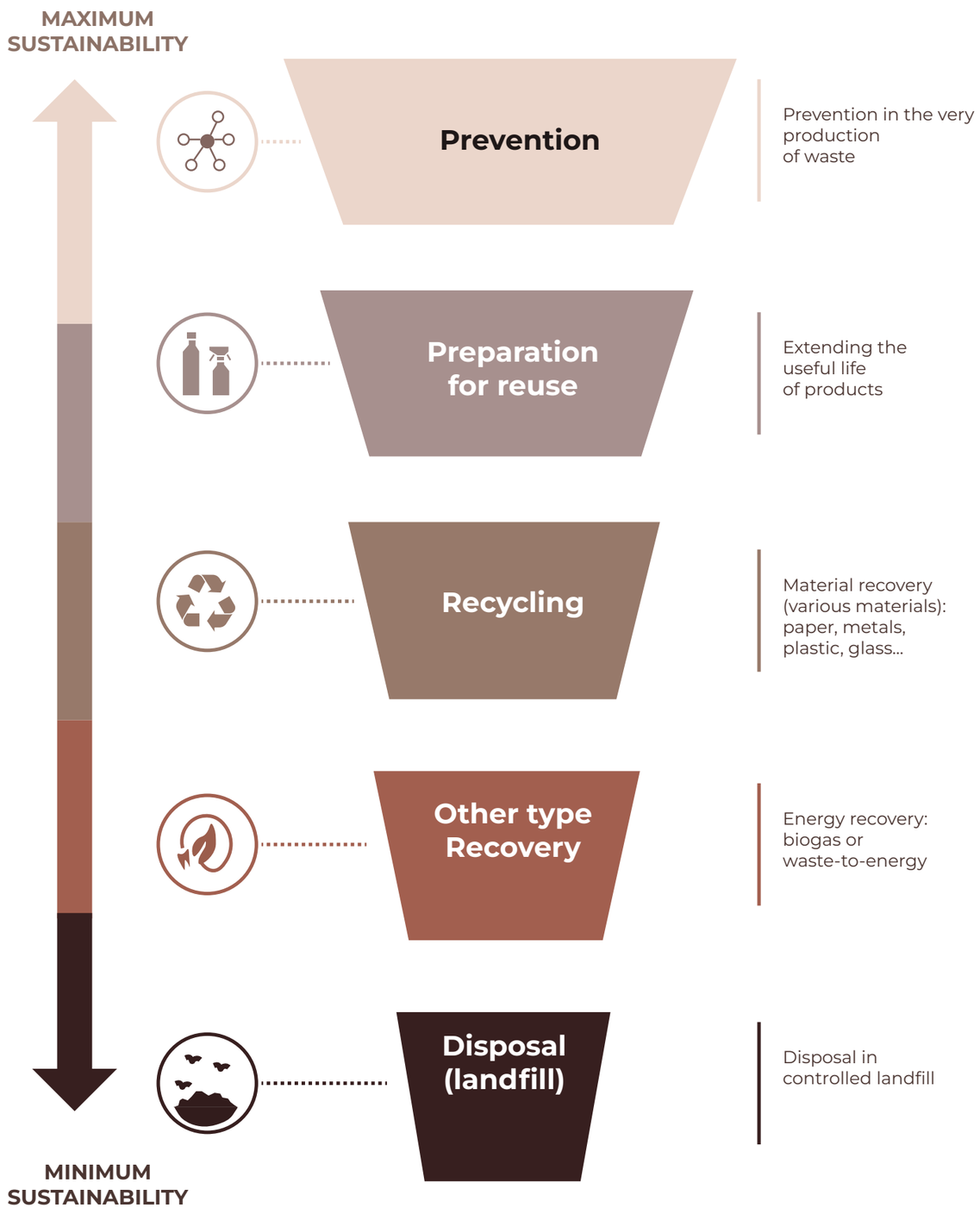


Fig. 18_The European waste hierarchy (Art. 4 of Directive 98/2008/EC and Art. 179 of Legislative Decree 152/06). Source: personal processing

The EU Protocol for Management of Construction and Demolition Waste

The integration of the EU Protocol on Construction and Demolition Waste Management constitutes a methodological benchmark within European circular economy policies. This protocol establishes the objective of advancing beyond linear approaches to building waste management, promoting the systematic valorization of anthropogenic stock.

A central element of this strategy is the transition to **selective demolition.** This practice redefines the decommissioning site as an urban extraction facility, where operations are systematically planned to preserve the chemical and physical integrity of materials. Unlike traditional demolition, which generates a heterogeneous mass of rubble, selective deconstruction involves the preventive separation of material flows, ensuring that each component is removed based on its intended future use.

This process begins with a **pre-demolition audit,** a technical and analytical assessment that must occur before any physical intervention. During this phase, qualified experts conduct a comprehensive mapping of construction elements, distinguishing hazardous materials, components suitable for direct reuse, and fractions intended for high-quality recycling. Early identification of critical substances, such as asbestos, lead, or polychlorinated biphenyls, is essential for isolating potential contaminants and preventing their dispersion, thereby preserving the purity of inert materials that may serve as secondary raw materials for the cement or infrastructure industries.

Operationally, selective demolition proceeds in the reverse order of construction, starting with the removal of non-structural elements, mechanical, electrical, and plumbing (MEP) systems, and interior finishes, and concluding with the dismantling of the load-bearing framework. This method improves site logistics and significantly reduces downstream sorting costs, as materials are pre-categorized into homogeneous fractions at the source. **Traceability** is therefore essential, linking the waste production site to the recovery facility and ensuring that technical documentation on material quality and origin accompanies resources throughout the value chain, thereby providing necessary safety assurances to end-users.

Although deconstruction requires longer execution times and more specialized labor compared to impact techniques, the EU Protocol emphasizes its overall economic sustainability. This sustainability derives from the residual value of recovered resources and cost savings associated with reduced landfill disposal fees for mixed waste.

This shapes the perception of building end-of-life, consolidating the concept of the building as a material bank and ensuring that closing the loop on construction materials is not simply an abstract environmental goal, but a consolidated and technically certified industrial practice.

The legislative issue of the “End of Waste”

The concept of End of Waste constitutes a pivotal and, in many respects, the most sensitive phase within the legislative framework of the circular economy. It delineates the intangible yet definitive boundary between waste management, which is subject to stringent controls, environmental traceability, and criminal liability, and the domain of products, which is regulated by market dynamics and technical performance standards. In the construction sector, this threshold serves as the essential gateway through which billions of tons of materials generated by demolition can avoid overwhelming landfills and instead regain commercial and technical value, enabling their reintegration into industrial processes.

The legal transformation of waste into a product is not automatic; rather, it is a process strictly regulated by **Article 6 of Directive 2008/98/EC**. According to this provision, waste ceases to be classified as such only after undergoing a recovery operation, which may range from basic technical inspection to complex regeneration, and meeting four essential cumulative criteria:

1. **Specific purpose:** The substance must be commonly utilized for defined applications. This criterion ensures that the cessation of waste status does not serve as a justification for introducing non-valuable materials into the market, but rather requires evidence of actual economic utility.

2. **Existing market or demand:** There must be a demonstrable market or demand for the substance, thereby confirming that the recovered material possesses genuine exchange value.

3. **Technical compliance:** The material must meet all applicable legal requirements, technical standards, and performance specifications relevant to comparable virgin products.

4. **Environmental and health protection:** The use of the substance must not lead to overall adverse environmental or human health impacts.

In the context of construction and demolition (C&D) waste, the application of End of Waste is complicated by the heterogeneous nature of the input materials. For recycled aggregates to transition from being classified as rubble to recognized building products, they must undergo separation, crushing, and screening processes that ensure the absence of hazardous contaminants, such as asbestos, PCBs, or heavy metals, and compliance with stringent geotechnical and chemical standards. The legislative challenge intensifies in defining specific criteria: in the absence of harmonized European regulations for each material category, Member States are required to issue national decrees specifying analytical thresholds. This situation has often led to interpretive uncertainty, compelling recovery companies to navigate a delicate balance between innovation and the risk of regulatory non-compliance.

Ultimately, the regulatory consolidation of End of Waste is an essential prerequisite for the development of a robust secondary materials industry. Legal certainty is necessary to attract investment for the establishment of technologically advanced treatment facilities that can ensure the purity and consistent performance of recovered resources. Addressing legislative barriers transforms demolition from an act of disposal into a source of supply, enabling the construction sector to operate within a continuous cycle in which the concept of ‘waste’ is replaced by the circular management of anthropogenic resources.

2.2. Technical Standards and free circulation of recovered materials

The effectiveness of the circular economy in the construction sector depends not only on technological capabilities for material recovery, but also on the reintegration of these resources into a transparent, secure, and barrier-free cross-border market.

Recovered materials should no longer be regarded as inferior alternatives or regulatory exceptions, but rather as mainstream industrial products. The primary barrier to this integration is performance uncertainty. Virgin materials benefit from standardized production processes and consistent chemical-physical properties, whereas materials from recovery or upcycling processes exhibit inherent variability that challenges existing certification procedures.

In this context, the concept of free movement of goods acquires a critical technical dimension. Eliminating barriers involves not only addressing tariffs and transportation, but more importantly, harmonizing safety and sustainability requirements.

Without supranational shared standards, there is a risk of market fragmentation, where the use of secondary components remains limited to local experimental protocols and lacks the capacity to impact the global industry. The regulatory challenge lies in translating environmental protection requirements into measurable technical parameters, thereby extending the concepts of durability and toughness beyond traditional lifecycle definitions. The regulatory framework calls for rethinking the link between conformity marking and usage performance. For re-used materials, especially those destined for structural functions, the guarantee of safety cannot prescind from a strict evaluation of residual properties and past loads. Therefore, surmounting technical barriers is a process of redefining reliability standards, aimed at demonstrating that sustainable innovation and structural stability can coexist within a modern regulatory framework capable of valorizing the infinite lifecycle of matter.



Fig. 19_Material Huband project of REBRICK di Gamle Mursten - Denmark, 2003. Source: *gamlemursten.dk*

The revision of the Construction Products Regulation (CPR)

The revision of the Construction Products Regulation (CPR) represents one of the most major milestones in the European construction industry's transition toward the paradigms of climate neutrality and resource circularity.

The earliest regulation, while facilitating the creation of a single market through a common technical language and CE marking, exhibited a structural gap by failing to consider environmental externalities as determining factors for a product's conformity. With the new regulation proposal, sustainability and durability are integrated as essential requirements defining the very suitability of a material for market placement. This transformation shifts the axis of certification from static, functional testing to the entire temporal span of the lifecycle, imposing a holistic vision on manufacturers that starts with the extraction of raw materials and extends through product end-of-life management and re-use potential.

From a sustainability standpoint, the revision introduces the systematic obligation to declare environmental performance through Life Cycle Assessment (LCA) methodology, effectively making the communication of carbon footprint and embodied energy consumption mandatory. This radical shift eliminates the information asymmetry that has historically disadvantaged products originating from recovery or upcycling supply chains: whereas in the past a regenerated material struggled to compete with a virgin product due to the lack of uniform testing protocols, the new CPR establishes uniform criteria for impact assessment, allowing the market to economically valorize components exhibiting a lower ecological debt.

Concurrently, the concept of durability is profoundly redefined and reinforced. While in previous legislation lifespan was an indirect parameter tied to structural stability in the short-to-medium term, within the new regulatory framework it becomes a pillar in the fight against planned obsolescence within construction. Products must be designed not only to withstand mechanical stresses, but also to maintain their performance characteristics unaltered for as long a period as possible, drastically reducing replacement rates. This emphasis on longevity is closely linked to design oriented toward disassembly and reparability: a durable material is such only if it can be maintained and, in the event of building demolition, removed without sustaining damage that would preclude a second cycle of use. Durability is thus configured as the technical precondition for structural upcycling, since only components with a certifiable residual useful life can be re-employed in new works without jeopardizing the reliability of the whole.

To support these new requirements, the CPR revision provides advanced operational tools such as the **electronic Product Passport** and the **digital compliance information system**. These mechanisms are destined to overhaul traceability along the value chain, providing architects, builders, and future demolishers with a detailed dataset concerning contained chemical substances, optimal maintenance procedures, and end-of-life restoration protocols. The introduction of harmonized standards for used and regenerated products also bridges a decades-long regulatory vacuum, establishing that a recovered component can be placed on the market with the same legal dignity as a new product, provided it satisfies updated performance and safety criteria.

Ultimately, the reform of the CPR does not simply regulate artifacts; rather, it redesigns the entire ontology of the construction material, transforming it from a static object destined for consumption into a dynamic resource capable of maintaining value and function across multiple lifecycles, while guaranteeing that the free movement of goods within the European Union remains inextricably bound to the safeguarding of ecosystems.

CE marking and the placing on the market of upcycling components

The CE marking (European Parliament and Council of the European Union, 2011) represents the keystone of the system for the free movement of construction products within the European single market, acting as a formal declaration of compliance with declared performance. However, when this instrument is applied to components derived from upcycling processes (meaning products that are recovered, regenerated, and reinserted into the economic cycle with a function equal to or greater than their original one) systemic frictions emerge between the rigid structure of the Construction Products Regulation (CPR) and the intrinsic variability of recycled materials. The fundamental challenge consists in the fact that the CE marking system was historically designed for linear industrial production, based on process repeatability and the constancy of virgin raw materials, conditions that are radically absent in the case of components extracted from existing buildings.

One of the principal regulatory barriers concerns the **attribution of legal liability** and **the definition of the manufacturer's role.** According to the CPR, anyone who substantially modifies a product or changes its intended use is equated with an original manufacturer, thereby assuming the burden of drafting the Declaration of Performance (DoP). For an operator practicing upcycling, this means having to guarantee the safety and reliability of an element whose exact technical genealogy is often unknown. The lack of original documentation, tied to buildings constructed decades before the entry into force of current harmonized standards, forces the entity intending to place the asset on the market to perform a sort of reverse engineering to reconstruct the mechanical, chemical, and physical properties of the component.

The core of the technical problem thus shifts to the **Assessment and Verification of Constancy of Performance (AVCP)** procedures. European harmonized standards (EN) prescribe standardized tests that often require destructive testing on statistically significant samples. In the context of upcycling unique architectural components or limited series (such as reclaimed steel beams or regenerated historical window frames), sacrificing a portion of the lot for laboratory testing proves economically unsustainable and technically counterproductive. Consequently, a regulatory paradox occurs: in order to certify the safety of a scarce resource, one risks destroying a significant portion of it, thereby nullifying the environmental benefit of the recovery. To overcome this impasse, the regulatory debate is shifting toward the acceptance of non-destructive testing methods and the use of evaluation protocols based on state-of-the-art computational calculations and artificial intelligence, capable of estimating residual performance starting from in situ surveys.

A further challenge is represented by the management of hazardous substances. Components destined for upcycling may contain residues of protective treatments, lead-based paints, or asbestos fibers, which are prohibited today but common in past constructions. CE marking mandates full transparency about the presence of such substances, requiring thorough chemical screenings that increase bureaucratic complexity and operational costs. Without simplifying these procedures for small batches or niche markets, CE marking risks transforming from a guarantee tool into a protectionist barrier that favors new products over regenerated ones.

In conclusion, the market placement of upcycled components requires an evolution of the regulatory framework able to integrate the concept of "product history" within quality certification. The challenge for European legislators is not simply to adapt existing standards, but to create compliance pathways that are flexible and proportionate to risk, where the CE marking can reflect not only a product's ability to withstand loads, but also its environmental value and regenerated integrity. Only through this process toward "circular certification" will it be possible to transform recovered components into standardized commodities capable of circulating freely across construction sites throughout Europe with the same legitimacy as newly manufactured industrial products.

The use of “second-hand” materials in structural elements

The use of recovered materials for structural purposes represents the most ambitious and tough challenge of contemporary civil engineering. While the use of secondary materials in non-load-bearing elements is now a consolidated practice, integrating them into a building’s structural framework demands overcoming technical barriers that touch on the very pillars of public safety and professional liability. The central issue is not a lack of material, but the management of uncertainty: whereas the virgin material industry guarantees constant quality standards by controlled processes, recovered material carries intrinsic heterogeneity and a prior history that must be decoded to be accepted in structural calculations.

The first step in solving technical barriers lies in **post-decommissioning performance characterization**. A “second-hand” structural element, whether a steel beam, a reinforced concrete pillar, or a timber portal, has undergone mechanical stresses, load and unload cycles (fatigue), and environmental aggressions such as corrosion, carbonation, or biological attacks during its first life.
To examine these elements without damaging their integrity, research is focusing on advanced Non-Destructive Testing (NDT) protocols. Techniques such as industrial computed tomography, multichannel ultrasonic testing, and active thermography make it possible to identify micro-cracks or hidden defects that would escape visual inspection. These data allow for a transition from an empirical assessment to an analytical determination of residual resistance, providing the designer with the scientific basis required for static testing sign-off.

An equally significant obstacle is represented by **statistical standardization**. Modern structural design codes, such as the Eurocodes (CEN, 2002), are based on probability-based approaches that demand exact knowledge of the distribution of resistance values. For recovered materials, data dispersion is naturally broader. Overcoming this barrier means adopting performance-based design methods, where the safety coefficient is not a fixed table value, but is recalibrated according to the quality and quantity of tests performed on the recovered batch. The application of Structural Health Monitoring (SHM) systems using Internet of Things sensors applied to re-used components can offer an additional guarantee, making it possible to observe the real behavior of the “second-hand” element over time and intervene preventively in the event of irregularities.

At the level of joint and connection design, surmounting technical barriers relies on the innovation of **fastening systems**. Recovered structural elements often have non-standard dimensions or drill holes inherited from previous assemblies that weaken their sections. The solution consists of developing adaptive interface components capable of coupling heterogeneous elements while ensuring the correct transmission of stresses. This strategy permits the recovered component to be treated as a module within a flexible system, decreasing the need for invasive on-site machining that might alter the thermomechanical properties of sensitive materials, such as legacy alloy steels.

Finally, the barrier of **traceability** and informational continuity is broken down through the deep digitalization of the supply chain. Surmounting technical diffidence is possible only if the recovered material ceases to be an unknown variable and becomes an object endowed with a digital identity. The use of Building Information Modeling (BIM) extended to the deconstruction phase makes it possible to create databases in which every structural element is cataloged with its load history, verified mechanical properties, and origin certifications.









Fig. 20_ Reusing structural steel in K118 Building - baubüro in situ, Switzerland, 2021. Source: *upcyclingarchitecture.it*

2.3. Digitalization and circularity measurement tools

For a long time, the inconsistency and fragmentation of data along the supply chain constituted the primary barrier to material recovery: the loss of information on technical properties, chemical composition, and the maintenance history of building components rendered a building's end-of-life a blind process, inevitably producing undifferentiated waste.

The transition from an analog approach to data-driven management of the built environment requires the development of rigorous measurement tools capable of translating the abstract concepts of sustainability into objective quantitative indicators.

Indeed, measuring circularity demands a systemic vision encompassing the entire lifecycle (Life Cycle Thinking), proceeding beyond traditional analyses centered solely on the building's operational phase. By consolidating evaluation systems harmonized at the continental level, it is now possible to precisely calculate the environmental impact of every single design choice, weighing the contribution of recovered materials against virgin ones not only in economic terms, but also in terms of CO_2 emissions savings and natural capital preservation.

The effectiveness of this measurement depends on the ability to preserve data persistence over time. Digitalization introduces revolutionary tools such as digital building logbooks and material passports, ensuring that the technical knowledge necessary for upcycling and structural re-use remains accessible to future operators, thereby eliminating the uncertainties that currently hinder the second-hand material market. Concurrently, the evolution of the European regulatory framework is rendering the reporting of embodied carbon footprint mandatory, shifting designers' focus toward the pre-construction phase and the selection of low-impact materials.



Fig. 21_Data-driven design applied to the Quay Quarter Tower - 3XN, Australia, 2020. Source: *3xn.com*

Level(s) and the evaluation of environmental performance

The Level(s) framework stands as the European Commission's most major initiative to standardize the reporting of building sustainability, acting as a veritable navigational system for the construction sector toward carbon neutrality objectives (European Commission, 2021). Developed through years of testing and consultation, Level(s) does not simply provide a list of best practices; rather, it establishes a framework of indicators based on Life Cycle Assessment (LCA) principles. Its ultimate purpose is twofold: on the one hand, to provide designers with a compass to optimize environmental performance; on the other, to offer stakeholders and regulators reliable and comparable data to reward genuinely circular buildings.

The structure of Level(s) is designed to be integrated into decision-making processes across three stages of project maturity, defined as **LEVELS OF APPLICATION.**

Level 1 (Conceptual Design)
serves to establish targets and evaluate the feasibility of sustainability strategies;

Level 2 (Detailed Design)
requires the detailed quantification of performance using simulations and technical calculations;

Level 3 (Post-completion / occupancy)
closes the loop by comparing design projections with the actual behavior of the built artifact once inhabited.

This progression makes it possible to address the performance gap, namely the deviation between the predicted efficiency declared in certificates and the actual environmental impact of the work during its useful life.

The framework is organized into **SIX MACRO-OBJECTIVES**, each dealing with a specific challenge of the ecological transition.

The first macro-objective concerns **greenhouse gas emissions throughout the lifecycle**, placing unprecedented emphasis on embodied carbon, the CO_2 emitted to produce, transport, and assemble materials. This constitutes a departure from the old logic that looked solely at operational consumption (heating and lighting), recognizing that in a highly energy-efficient building, the largest share of impact shifts precisely to the matter itself.

The second macro-objective is dedicated to **circularity and resource efficiency**.
Here, Level(s) introduces specific indicators to measure the recoverability of materials, ease of dismantling, and deconstruction capability. This approach incentivizes the adoption of Design for Deconstruction (DfD), transforming the building into a reversible assembly of components rather than an inert mass.

Other fundamental objectives concern **efficient water use**, the **creation of healthy indoor spaces** (thermal comfort and air quality), **adaptation to upcoming climate change**, and, finally, **Life Cycle Costing (LCC)**, which evaluates the long-term economic sustainability of the building, including maintenance and disposal costs.

Embedding Level(s) into the legislative landscape is powerful: it serves as the technical basis for the European Taxonomy, defining the criteria to determine whether a real estate investment can be considered "green" and thus deserving of financial incentives.

Furthermore, its methodology has been absorbed into the recast Energy Performance of Buildings Directive (EPBD IV), making the assessment of **Global Warming Potential (GWP)** mandatory for new constructions. Ultimately, Level(s) transforms architecture from an aesthetic and functional exercise into a scientific discipline of data, in which every gram of matter and every kilowatt-hour are accounted for within a precise planetary balance, guaranteeing that sustainability is not simply a marketing claim, but a certifiable and scalable technical performance.

Digital Building Logbooks and Digital Material Passport (DPP)

Digital Building Logbooks (DBLs) and Digital Product Passports (DPPs) constitute the data infrastructure necessary to move beyond the current management of the building stock. Whereas architecture has historically been defined by a chronic loss of information between the construction site phase and decommissioning, the advent of these software tools creates an informative thread that preserves the value of matter over time. This represents a true documentary revolution: the building ceases to be an inert mass of unknown components and becomes a dynamic archive, in which every gram of resource is accounted for, localized, and qualified.

The **Digital Building Logbook (DBL)** is conceived as an integrated digital ecosystem that collects, organizes, and makes accessible all information produced throughout the entire lifecycle of a built artifact. It is not limited to being a static repository of graphic drawings or administrative certifications; the DBL is an evolving tool that aggregates Building Information Modeling (BIM) models, historical maintenance data, actual energy consumption monitored via sensors, and structural modifications occurring over time. This "black box" of the building allows owners and managers to optimize operational performance and plan predictive maintenance interventions, extending the useful asset life and preventing the premature degradation that often leads to early demolition.

Within the Logbook, the **Digital Product Passport (DPP)** operates at a more granular scale, acting as a digital identity of every single component or construction product. The DPP answers the fundamental question of the circular economy:

"what is this element made of, and how can I recover it?"

Each passport contains critical data such as detailed chemical composition (essential for guaranteeing the future absence of toxic substances), certified mechanical performance, the percentage of recycled content, and, above all, instructions for dismantling and end-of-life. Thanks to unique identification technologies like RFID tags, QR codes, or blockchain-based systems, it is possible to query a structural element or finish even decades after installation, instantly obtaining the specifications necessary for its safe re-use.

The assembly of these tools enables a fundamental change toward Urban Mining on a territorial scale. When Digital Building Logbooks are harmonized at the urban or regional level, public administrations and economic operators can rely on a predictive map of material flows. It becomes possible to forecast with precise accuracy when and where specific quantities of steel, glass, or structural timber will become available, enabling the creation of stable and reliable secondary raw material markets. This breaks down one of the main barriers to circularity: uncertainty regarding the availability and quality of recovered materials.

Furthermore, the Digital Product Passport serves as the operational arm of Extended Producer Responsibility (EPR) (European Parliament and Council of the European Union, 2008). By compellingly requiring manufacturers to input transparent data on carbon footprint and recyclability, the DPP discourages greenwashing and pushes the industry toward eco-design. A building equipped with a DBL and DPP acquires superior asset value, since its residual value is no longer an abstract estimate, but a calculable figure based on the quantity of re-usable resources contained within it. Ultimately, the digitalization of the building stock transforms knowledge into economic value, guaranteeing that matter never again returns to being anonymous waste, but stays a perpetual resource within a transparent and traceable economic system.

The Global Warming Potential (GWP) and the EPBD IV Directive

The introduction of the mandatory calculation of Global Warming Potential (GWP) across the entire lifecycle of buildings, enshrined in the Energy Performance of Buildings Directive (EPBD IV), represents the definitive transition from a climate policy based exclusively on consumption containment to a strategy of absolute decarbonization of the built environment (European Parliament and Council of the European Union, 2024). For decades, European legislation (from the early versions of the EPBD up to NZEB) focused its efforts on operational emissions. However, with increasing system efficiency and the electrification of consumption, the share of environmental impact generated by material production and construction itself (the so-called embodied carbon) has become predominant, accounting for over 50% of the total emissions of a high-performance new building.

EPBD IV intervenes on this disequilibrium by mandating the measurement of **Life Cycle GWP**, an indicator that measures the climate impact of the built artifact from cradle to grave.

This calculation must be performed following the Life Cycle Assessment (LCA) methodology, structured according to the phases defined by the EN 15978 standard:

- **Product Stage (A1–A3):** raw material harvesting, factory transport, and component manufacturing.
- **Construction Process Stage (A4–A5):** transport to the construction site and installation processes.
- **Use Stage (B1–B7):** emissions linked to operation, as well as maintenance and component replacement.
- **End-of-Life Stage (C1–C4):** demolition, waste transport, and disposal.
- **Benefits Beyond the Life Cycle (D):** the potential for recovery, re-use, and recycling that "credits" the total carbon footprint.

The mandatory nature of this parameter transforms GWP into a design metric on par with cost or structural resistance. For designers, this means balancing thermal performance with material impact: for example, adding excessive thicknesses of synthetic insulation might save operational energy, but generate an embodied carbon footprint that can never be offset during the building's useful life. In this context, the calculation of GWP becomes the most powerful driver for circularity: the use of recovered materials or re-used components has an almost negligible impact in terms of GWP during stages A1–A3 (since their carbon debt was settled in their first lifecycle), making circular strategies not merely ethically preferable, but regulatory advantageous.

The roadmap outlined by EPBD IV is clear: starting in 2028, the calculation obligation will apply to all new buildings with a usable floor area exceeding 1,000 square meters, while from 2030 the measure will be extended to all new constructions, regardless of size. This transparency, which will see GWP integrated into Energy Performance Certificates (EPCs), will help create the continental database needed to establish binding maximum emission limits per square meter in subsequent years.

The impact of this directive goes beyond construction technique, immediately influencing the real estate and financial markets. A building with a low lifecycle GWP becomes a low climate-risk asset, aligned with EU Taxonomy criteria and more attractive to institutional investment funds. To summarize, the introduction of mandatory GWP marks the end of the era of isolated energy savings and inaugurates that of integrated environmental accounting, where the quality of an architecture is measured by its capacity to exist without eroding the remaining planetary carbon budget, valorizing existing matter through re-use and reversible design.

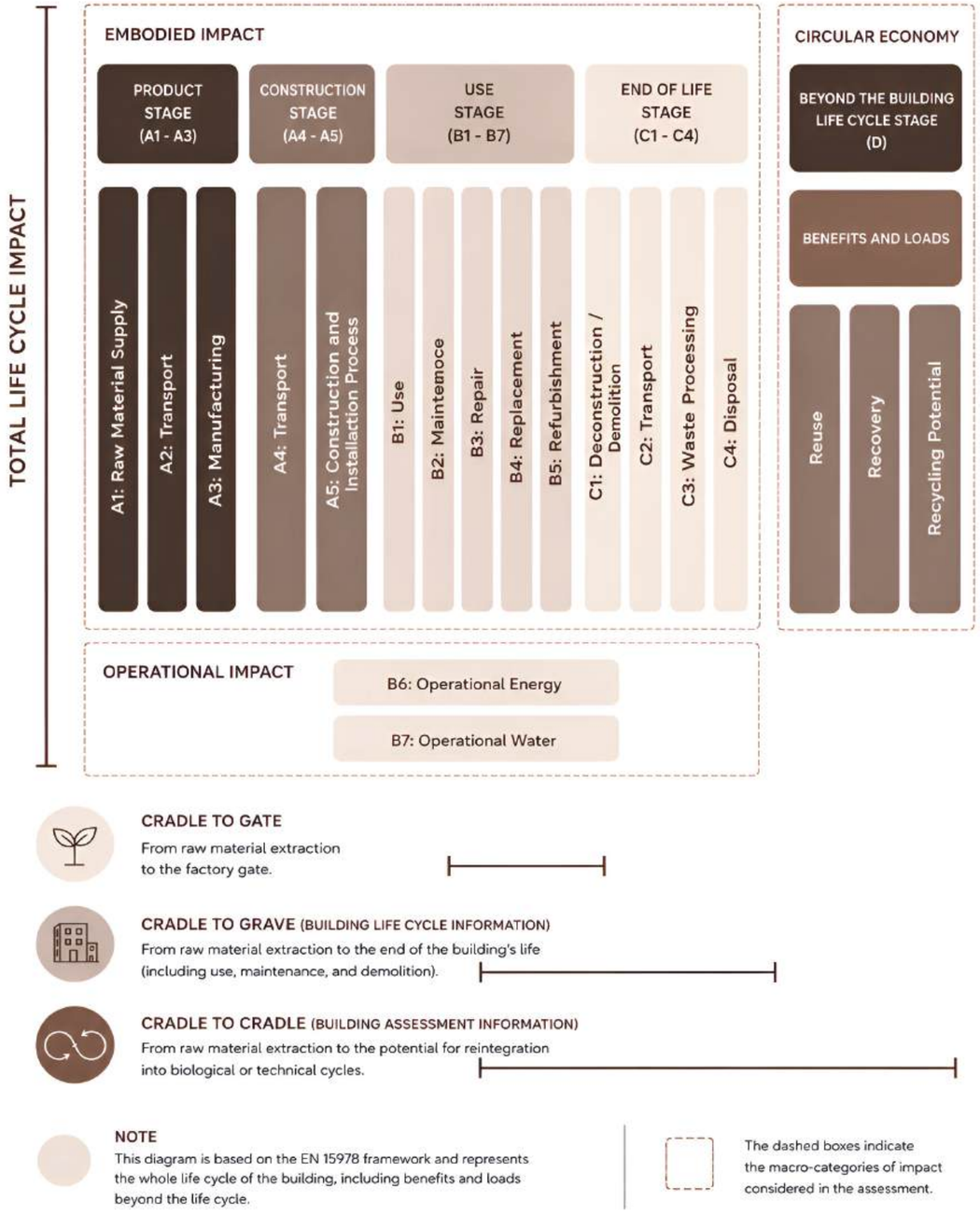


Fig. 22_Life Cycle Assessment. Source: *personal processing*

2.4. Geographies of the possible: London, Copenhagen and Italy

The international scene of upcycling configures itself as a complex and fragmented collage of “geographies of the possible.” On this global chessboard, the capacity to translate ecological urgency into constructive reality depends upon the degree of friction exerted by differing national regulatory, fiscal, and cultural systems.

Discarded architectural matter today experiences diametrically opposed destinies depending on the legislative latitude in which it happens to transit: while in some contexts it is elevated to a strategic resource and primary economic asset, in others it remains limited within the degrading limbo of waste, the victim of bureaucratic stagnation that systematically suppresses its every potential toward reinvention.

While Northern Europe and the Anglo-Saxon world are pragmatically structuring cutting-edge legal infrastructures, the Italian context still appears dangerously trapped in a defensive and punitive view of the norm. In Italy, the dogma of standardized performance and the obsession with the certification of the “factory-new” act as an insurmountable customs barrier against regenerative innovation.

This gap not only produces incalculable environmental damage in terms of emissions and land consumption, but digs a deep competitive and cultural chasm among nations.

The methodical comparison that follows between the metropolitan realities of London, the Scandinavian ecosystem of Copenhagen, and the complex Italian panorama does not aim to be a mere descriptive review of excellence case studies, but presents itself as a systematic investigation into how construction policy determines, in practice, the success or failure of the ecological transition. Analyzing these geographies means mapping the invisible resistances and courageous openings of systems which, despite starting from the identical EU directives and the exact same decarbonization objectives for 2050, have generated diametrically opposed operational practices and architectural languages.



Fig. 23_Structural Upcycling Applied at Goldsmiths CCA - Assemble, London, 2018 Source: *divisare.com - Andy Keate*

The Anglo-Saxon model: residual value reporting

Within the worldwide landscape of urban regeneration, the United Kingdom stands out for having executed a fundamental paradigm shift that merits in-depth analysis: the approach to circularity has officially moved beyond the embryonic phase of simple waste management (too often understood exclusively as a logistical, regulatory, and environmental burden) to arrive at a dimension of advanced governance. This configures itself as a structure oriented toward total traceability and the economic valorization of decommissioned components, transforming the concept of end-of-life into new availability.

Despite the deep political and administrative break represented by Brexit, London and major British cities have not isolated themselves; on the contrary, they have maintained a line of strict conformity with European directives on the waste hierarchy, grasping them as a legal foundation to evolve advanced and globally competitive real estate management tools.

This process of bureaucratic and technical metamorphosis has taken place through the systematic implementation of **Material Passports**. Strongly promoted by the **UK Green Building Council** (UKGBC, 2020), these tools have been natively integrated into BIM (Building Information Modeling) workflows, transforming digital data into a patrimonial asset. Such passports must not be understood as mere passive technical data sheets or static information repositories; they are true digital and dynamic "vehicle registration documents" that accompany every single structural and architectural component throughout its entire lifecycle. Their critical function is to document with meticulous accuracy the origin of the raw material, certified structural performance at origin, maintenance undergone over time, and, above all, future re-use potential. The latter is calculated via algorithms that evaluate residual wear and the reversibility of joints, allowing the material's marketability to be known in advance.

The most major point of departure from the continental European model, and particularly from the rigidity of the Italian context, lies in the British capacity to integrate sustainability demands with financial and insurance market metrics. UK regulations are gradually introducing the mandatory reporting of Whole Life Carbon using rigorous technical standards such as the **RICS Professional Statement on Whole Life Carbon Assessment.** In this system, project evaluation is no longer confined solely to operational energy efficiency (i.e., emissions linked to heating and cooling consumption) but encompasses total carbon impact. This prominently includes the embodied carbon sequestered in materials already in place, making the conservation of matter a financial choice before an ecological one.

From this perspective, the act of demolishing a structurally sound building ceases to be a lot cleanup practice and transforms into a financially risky and penalizing operation. Indeed, the client is forced to declare a massive loss of existing carbon capital and to bear, within the project's environmental budget, the emission costs associated with new steel or concrete production. This **moral and accounting taxation** shifts the axis of convenience toward conservative recovery and upcycling.

The case of the Euston Tower in London appears as the plastic and iconic example of this new "geography of the possible." Here, the redevelopment intervention was not conceived as an act of consumption or anthropogenic tabula rasa, but as an operation of controlled, high-precision urban extraction. The entire skyscraper was treated by the design team not as an artifact of the past century to be disposed of, but as a "Building as a Material Bank" (BAMB), where each floor represents a deposit of ready-to-use resources.

British regulation, proving more agile and less punitive than the Italian one in defining the labile boundary between waste and resource, has facilitated processes of mechanical in situ regeneration of extremely complex technological components. The aluminum frames of curtain walls, for instance, were not sent to the foundry for raw material recycling (a process that, while virtuous compared to extraction, requires enormous energy input and generates new process emissions) but were disassembled, decontaminated, checked for performance tolerances, and reassembled in the same location or in new configurations. This approach made it possible to fully preserve the embodied energy, avoiding the extraction and refining of tons of new virgin metal and drastically reducing the carbon footprint of the construction site.

From a critical analysis standpoint, the success of such operations is guaranteed by a regulatory system that has begun to recognize and codify the legal value of residual performance. In the United Kingdom, the application of standards such as **BS 8895** (concerning design for manufacture, assembly, disassembly, and end-of-life) is establishing a normative bridge between the designer's civil liability and the safety of the recovered component (British Standards Institution, 2013). In essence, the law permits professionals to work on secondary structural elements by providing legal, insurance, and testing guarantees comparable to those required for new materials. This is possible provided that the validation process follows rigorous non-destructive diagnostic protocols and continuous structural monitoring, shifting the emphasis from "factory certification" to "verification certification."

In conclusion, the Anglo-Saxon model clearly demonstrates that structural upcycling can finally emerge from the niche of environmental activism or experimental exceptionalism only if it is transformed into a controllable and profitable economic and legal variable. By making carbon accountable and matter traceable via digital passports, the United Kingdom is converting what elsewhere is a paralyzing legislative bottleneck into a driving force for urban regeneration. The designer is no longer called upon to be the demiurge who invents a form out of nothing, but the expert curator who manages a complex inventory of pre-existing resources, minimizing the dissipation of energetic value and transforming the construction site into an act of conscious planetary maintenance. This vision shifts the accent from the certification of the new industrial product to the certification of the care and verification process, definitively legitimizing architectural waste as a noble, safe, and technically reliable material for forthcoming challenges.

The Scandinavian Ecosystem: Obligation for Deconstruction

If Denmark, and particularly the metropolitan area of Copenhagen, is universally recognized today as the global epicenter of experimentation in structural upcycling, this is not due to a fortuitous aesthetic conjuncture or isolated architectural sensitivity, but rather the outcome of a precise, coherent, and radical political engineering of matter. The Scandinavian model distances itself from the systems of Mediterranean Europe through a fundamental philosophical and ontological transition: moving beyond punitive waste management in favor of an active policy toward pre-existing resources. While in many European countries, and particularly in Italy, the regulation intervenes only ex-post (i.e., when the building has already been reduced to formless rubble and environmental damage is irreversible), the Danish system acts ex-ante. It redefines the very concept of real estate property and built artifacts, no longer viewed as static volumes destined for the oblivion of demolition, but as temporary repositories of high-environmental-value materials, components of an urban material bank waiting only to be harvested and reinvested.

This regulatory metamorphosis finds its backbone in the national strategy for the circular economy, which reached its maximum technical expression in the revision of the **Building Regulation (BR18**) and subsequent integrations planned for the 2025–2026 biennium (Danish Building Regulations, 2022). The disruptive novelty of this system does not lie exclusively in the provision of incentives, but rather in the introduction of a procedural obligation that radically dismantles the practice of traditional demolition. The regulation on selective deconstruction transforms mechanical tearing down (historically considered a rapid, swift process intended at clearing land) into a mandatory and scientifically codified "urban extraction" process.

Under the new directives, the issuance of a demolition permit is conditional upon the submission of a binding **Pre-Demolition Audit.** This is not simply a quantitative waste estimation or an administrative formality, but a rigorous qualitative mapping that must identify material purity, the typology of joints (discriminating between reversible connections like bolted ones and irreversible bonds like welding), and the presence of any contaminants that might preclude re-use. This audit transforms potential waste into an inventoried product before the building is even physically touched. In other words, Danish law acts upon the deep psychology of the supply chain: the moment a material is mapped and cataloged as a re-usable resource in an official document, abandoning it or crushing it into inert matter ceases to be standard practice and becomes a concrete economic loss and a violation of environmental compliance.

A further critical element that the Scandinavian model has successfully resolved concerns the chronic cost imbalance, the primary cause of upcycling failure in contexts such as Italy. If demolition is cheap due to a market that does not pay the price of its externalities, dismantling requires very high intensity of specialized labor and prolonged timelines. Denmark tackled this paradox through an intentional restructuring of fiscal levers, exploring the introduction of differentiated VAT and specific tax credits to compensate for the burden of selective dismantling.

Scandinavian political analysis stems from a premise of climate justice: virgin matter currently appears artificially inexpensive solely because its market price omits the social and environmental costs of CO_2 emissions generated during extraction and refinement. The state therefore intervenes to internalize these externalities, making upgraded waste not only ethically preferable but also economically competitive against virgin industrial products (Nordic Council of Ministers, 2020). This policy transfers the axis of investment from the destructive consumption of natural resources toward the valorization of qualified human labor, incentivizing the emergence of new professional figures: material curators and deconstruction technicians, custodians of a new artisanal wisdom applied to the tectonics of recovery.

Parallelly, Scandinavian success rests on solving the Gordian knot of technical responsibility and guarantees. While in Italy the lack of an original CE marking on a recovered element systematically blocks static testing, the Danish Transport, Construction and Housing Authority has worked on creating **"second-life" certification protocols** (ETA Danmark, 2021). These allow third-party bodies to validate the residual performance of a component through non-destructive diagnostic tests, legally equating it to a new product.

This regulatory lubrication eliminates the legal and insurance uncertainty that paralyzes designers and businesses. Where other countries view re-use as an unmanageable civil liability risk, Denmark views it as a necessity for standardizing recovery: it is the ultimate victory of performance-based diagnostics over bureaucratic paperwork. The material is not considered safe because it possesses a paper factory certificate, but because it has been tested, verified, and validated in its actual current condition.

Finally, one must investigate the cultural root of this geographical asynchrony to fully grasp the scale of the challenge. In Scandinavia, sustainability has ceased to be perceived as a limit to creative freedom or an economic sacrifice, becoming a new institutionalized aesthetic and social canon. Danish policy has successfully ennobled the patina of time, transforming the blemishes and stratification of recovered material into a sign of ethical prestige and architectural quality. While in other contexts the new remains the sole acceptable synonym of quality and well-being, in Copenhagen the traceability of matter endows the building with a material "biography" that increases its real estate value and feeling of collective belonging.

The Scandinavian ecosystem clearly demonstrates that implementing upcycling requires more than innovative architects; it demands courageous and progressive governance. The ongoing transition is neither merely technical nor stylistic; it is profoundly political: deciding, ultimately, whether the legislative apparatus should continue protecting the linear interests of virgin matter production or stand in defense of the biosphere through the care, maintenance, and constant metamorphosis of what already exists.

The Italian case: the paradox of performance rigidity

Unlike Northern European and Anglo-Saxon models, which have efficiently integrated circularity into a pragmatic, accounting-driven vision of resources, Italy today presents itself as a territory marked by severe, paralyzing systemic asynchrony. Although national political rhetoric insistently proclaims the necessity of an ecological transition, the regulatory and bureaucratic apparatus remains anachronistically anchored to a linear economic model, where the dogma of virgin matter exists as the sole standard of technical reliability. This difference between declared climate objectives and the operational tools actually available generates a structural isolation of innovation: in Italy, upcycling is not yet a practice, but a form of resistance against a bureaucracy that seems designed to favor extraction rather than conservation.

The core of this critical issue resides in a sort of ontological blindness within Italian legislation, which prevents the recognition of a building component's value once it is detached from its original architectural organism. In the national context, the transition of a building component into waste is an almost instantaneous and, unfortunately, legally irreversible process.

This strictness manifests forcefully when attempting to apply the CE marking to a recovered element. The protocols developed for the **Declaration of Performance (DoP)** were conceived for serial industrial production, where quality control takes place at the source on samples of new raw material (European Parliament and Council of the European Union, 2011). This logic inevitably collides with the nature of upcycling, in which every piece carries a unique "biography," defined by endured loads and the patina of time. In the absence of technical standards (such as NTC 2018) that legitimize non-destructive testing procedures to recertify used components, testing engineers and designers find themselves operating in a hazardous legislative vacuum that shifts the entire civil and criminal liability of any intervention onto them.

This condition of uncertainty drives a **regulatory lag** that systematically penalizes the pioneers of urban regeneration. Paradoxically, safety legislation thus ends up incentivizing the consumption of new land and new resources, because purchasing a virgin beam guarantees a "bureaucratic peace of mind" that existing matter, however noble, cannot offer.

Critical analysis must also extend to the ineffectiveness of transition tools such as the End-of-Waste mechanism. In Italy, the cessation of waste status is still managed through decrees that focus almost exclusively on coarse downcycling, namely, crushing rubble to use it as road sub-bases. There is a complete lack of a framework that allows a complex structural component to change status while preserving its official integrity. This shortcoming leaves room for interpretive discretion by local authorities who, out of fear of environmental offenses, often adopt ultra-conservative approaches, blocking any attempt to industrialize structural re-use.

Without a fast track that technically legitimizes upgraded waste, upcycling in Italy remains confined to isolated episodes or academic experiments, lacking the scalability necessary to impact urban metabolism. While official data confirm that the majority of construction waste is recovered, deeper investigation shows that this is low-value-added recovery, which merely delays the material's entry into the landfill by a short margin. Elevating the conservation of matter to a regulatory priority is therefore not simply a technical issue, but an act of resistance: as long as the dogma of the new remains the pillar of our bureaucracy, the beauty of regeneration will remain a utopia suffocated by a law that, in seeking to protect the user from structural risk, ultimately condemns the entire system to climate risk.

Towards a technical legitimation of waste

The comparison among these "geographies of the possible" brings to light an uncomfortable and unavoidable fact for contemporary architecture: the true challenge of the ecological transition is no longer technological, nor strictly design-oriented, but rather exquisitely bureaucratic, regulatory, and political.

We find ourselves confronted with a structural paradox that demands a rigorous reflection:

Is it possible that bureaucracy, historically born as a safeguard for safety, public health, and performance quality, has transformed today into the main obstacle to both aesthetic excellence and ecological survival?

To bridge the abyss separating Italy from European avant-gardes, timid procedural adjustments, explanatory circulars, or ad hoc exemptions granted on an emergency basis are no longer sufficient; a radical and systemic reform of building codes and Technical Regulations for Construction (NTC) is necessary, enacting a genuine ontological promotion of recovered matter. Upcycled material must cease to be perceived and regulated as a poor surrogate, a fallback choice destined for marginal projects, and instead be formally recognized and codified as a high-end component. Such elevation is neither an aesthetic caprice nor a romantic instance, but an act of thermo-dynamic justice: it means attributing legal and technical value to the carbon capital and embodied energy that said material successfully sequestered from the atmosphere decades ago and continues to incorporate. In a planet characterized by finite resources, matter that has already passed the test of time and load should enjoy a presumption of suitability and a preferential track, rather than a juridical mark of infamy that mandates its pulverization.

This technical legitimization can be concretely achieved only through the adoption of a digital traceability infrastructure that replaces blind (and frequently fallacious) trust in the "paper mill certificate" with the granular transparency of historical and performance data.

Embedding Material Passports within BIM workflows represents the sole valid path to objectify the residual performance of a component. Turning waste into a resource entails endowing it with a digital mechanical biography that attests to its provenance, past stress loads, and chemical compatibility with novel use cycles.

Concurrently, a courageous and non-punitive revision of End-of-Waste criteria is indispensable. Legislation must evolve from the management of amorphous rubble (the so-called downcycling that degrades value) toward the protection of intact and complex components. It is necessary to permit a steel beam, a stone portal, or a still-performant window frame to change ownership and planned use without necessarily enduring the juridical humiliation of downclassification as special waste, along with all associated costs and complications.

Ultimately, aligning Italy with the most advanced geographies of regeneration implies executing a cultural and paradigmatic leap: we must cease considering the management of decommissioned materials as a logistical and bothersome appendix of the construction site, transforming it instead into a true tectonics of the existing.

The architect of the future can no longer be understood as the demiurge who designs forms ex nihilo by drawing from an infinite catalog of virgin products, but must act as a curator of urban material deposits. They must become an interpreter capable of reading within the detritus a resource that is readily available and technically reliable. Only by dismantling the bureaucratic barriers that currently render upcycling a heroic, risky, and uneconomical endeavor can Italy cease devouring its territory compulsively and finally begin inhabiting its material memory. Only thus will beauty cease to be a consumption of the world, becoming the outcome of constant care and the perpetual metamorphosis of existing matter.

CHAPTER THREE

03

Case studies: critical and technical analysis of upcycling

3.1. Analysis methodology

By examining realized interventions (or advanced design scenarios that push the limits of innovation), this text attempts to understand how the “Tectonics of the Existing” can translate into a new aesthetic of constancy and re-use.

The objective is to map the adopted solutions with the aim of transforming recovery from an isolated experimental exception into a codifiable and scalable professional practice. Indeed, the following case studies outline the course for a future professional practice, a practice in which the architect is no longer solely a creator of abstract forms, but a curator of resources in transit, capable of orchestrating the lifecycle of materials within an urban metabolism that is finally circular and regenerative.

The in-depth analysis will therefore unfold across three levels of reading:

· The extractive level: how matter is extracted from the donor building through selective deconstruction protocols;

· The performance level: the tests and testing and validation processes that transform waste into a certified structural component;

· The compositional level: the linguistic challenge of designing with pre-finished and pre-dimensioned elements, accepting the rule of the component as a creative stimulus rather than a limit.

Only through this examination will it be possible to demonstrate that structural upcycling is not simply necessary to achieve the climate objectives of 2030, but represents the only true evolution possible for an architecture that wishes to call itself authentically contemporary.



Fig. 24_Rotor DC: reuse made easy - Rotor, Bruxelles, 2016. Source: *rotordb.org*

Sample selection criteria

The practical validation phase of this research is structured through the critical analysis of a series of architectural interventions selected according to criteria of technical, procedural, and regulatory exemplarity.

The objective is not to provide an encyclopedic review of sustainable projects, but rather to construct an operational atlas of upcycling capable of demonstrating the feasibility of the regenerative paradigm across several scales of complexity.

The sampling was defined on the basis of four fundamental methodological vectors:

1. SCALABILITY

The selection of case studies aims to dismantle the entrenched critical prejudice that relegates upcycling solely to the dimension of self-construction, ephemeral micro-architecture, or experimental interventions isolated from the logic of the real market. Conversely, the research intends to demonstrate that the creative re-use of matter is a scalable practice, capable of adapting to and responding to the different performance requirements of the entire spectrum of contemporary building production. The sample has therefore been stratified according to a progression of complexity that reflects three different approaches to the architectural scale:

· The micro-scale and the architecture of the ephemeral:
focusing on how upcycling can transform the temporary event as an opportunity for dynamic resource storage.

· The residential scale and the challenge of seriality:
demonstrating how material recovery can emerge from the niche of craftsmanship, be industrialized, and become economically competitive in the mass real estate market.

· The macro-scale and the regeneration of tertiary heritage:
examining large-scale interventions, addressing the now indispensable theme of regenerating skyscrapers and complicated structures inside dense city centers.

2. SPECIFICITY AND INNOVATION

Each case study was selected as a pilot project capable of presiding over a specific recovery supply chain, delivering concrete solutions to the problem of material value degradation. The analysis focuses on the capacity of these interventions to effect a true metamorphosis of waste, transforming it into a resource endowed with new architectural dignity through the innovation of construction details and site logistics:

· The structural re-use of reinforced concrete: to address the most difficult challenge of the ecological transition in construction: the recovery of reinforced concrete. The objective of the analysis is to demonstrate how it is possible to preserve the structural strength of components for their direct re-use in new buildings, avoiding traditional downcycling that reduces concrete to simple aggregate for road sub-bases.

· The functional metamorphosis of secondary components: to analyze how heterogeneous and technologically obsolete building components can be functionally reinterpreted.

· The valorization of timber and glass supply chains: where innovation consists in the capacity to certify and test materials considered waste, such as cross-laminated timber scraps or double-glazing units from selective demolitions.

3. WORKFLOW INVERSION

A decisive criterion in selecting the sample was the radical methodological approach adopted by the studios involved (such as Superuse Studios, SLA, Lendager, and 3XN/GXN), which propose moving beyond the linear design-construction process. These case studies were chosen because they document an epistemological inversion of the project, where the architect acts not only as a composer of forms, but as a curator of material flows:

· From form to resource (and vice versa):
The selection analyzes projects where architectural form is no longer a priori data established on industrial standards, but emerges dialectically from the availability, geometries, and physical characteristics of materials procured locally through urban mining practices. This approach remodels the constraint of waste material into a generative opportunity, defining a new tectonics of the existing in which construction detail must be flexible enough to accommodate fluctuations in the recovered resource.

· Management of temporal asynchrony:
One of the key criteria for choosing these cases is their capacity to provide operational responses to the problem of asynchrony between the demolition phase (material supply) and the construction phase (demand). The analysis focuses on how these studios manage the rhythm of materials, utilizing the project itself as a temporal lung. Through these examples, the research studies the need for new logistical and storage models that synchronize urban material flows, transforming the city as a dynamic warehouse of perpetually available resources.

· Application of digital tools and mapping:
The selection allows for an in-depth look at the use of new digital tools, such as material passports and material mapping platforms, which are necessary for tracking the provenance, quality, and re-use potential of elements.

· Redefinition of the professional role:
Finally, these cases were chosen to illustrate the fundamental evolution of the architect's figure, who in these contexts assumes the role of "supply chain mediator." The analysis shows how the upcycling project requires continuous negotiation between architectural vision and the physical reality of urban depots, redirecting focus from object creation to managing the lifecycle of matter.

4. GEOGRAPHY AND TRANSFERABILITY

The final selection criterion responds to the need to compare the theory of upcycling with the reality of international regulatory systems. The choice to focus the investigation on specific Northern European contexts and the United Kingdom is not dictated by geographical preference, but by the nature of these territories as true legislative laboratories and procedural avant-gardes:

· Contexts of excellence as laboratories of the possible:
Denmark, the Netherlands, Norway, and the United Kingdom represent ecosystems where the flexibility of technical protocols and the presence of structured markets for secondary materials render upcycling an operational practice rather than a mere experiment. Analyzing these cases allows for the observation of active "resource certification" models, where recovered material enjoys performance guarantees comparable to virgin materials, facilitating the acceptance of risk by investors and insurers.

· The contrast with the Italian regulatory system:
The comparison between these international experiences and the national context highlights the systemic criticalities of the Italian framework. In particular, the investigation dwells on the complex bureaucracy linked to the cessation of waste status (End of Waste), which in Italy often represents an insurmountable obstacle to circularity. These case studies therefore act as benchmarks to measure the gap between the technical potential of architecture and the limits imposed by environmental legislation that still struggles to distinguish between waste to be disposed of and resources to be valorized.

· Delineation of simplification proposals:
The ultimate purpose of this geographical criterion is to verify the transferability of the observed models. The analysis is not limited to considering foreign best practices, but aims to extrapolate procedural and technical strategies that can be adapted to professional practice nationwide. In the thesis conclusions, these data will be fundamental for formulating a regulatory and administrative simplification proposal that allows upcycling to break out of the elite niche and become a legal, widespread practice of urban regeneration in Italy.

Critical analysis parameters

To ensure an analysis that is not simply descriptive but has modeling and comparative value, each intervention has been decoded through an investigative grid structured into six analytical dimensions. The dimensions of inquiry adopted for the examination of the case studies are the following:

1. Genesis (Data and Methodology)
This first dimension of inquiry constitutes the phase of intellectual deconstruction of the project and aims to unveil the philosophical and operational assumptions that guided the regenerative approach, moving beyond the simple cataloging of dimensional or quantitative data. The analysis focuses on understanding how the earliest architectural vision was deeply influenced, and at times radically deflected, by the intrinsic nature and immediate availability of the recovered matter. The core of this section lies in the analysis of the systemic inversion of the traditional design workflow, which usually proceeds linearly from concept to form and only finally to material selection. In the selected case studies, a rupture of this sequence is observed instead: urban mining activity and territorial material sourcing precede and inform the definition of the architectural design, making the form a dialectical resultant between the functional requirements of the building program and the physical, geometric, and performance characteristics of the recovered resources. The ultimate objective of this analysis is to map the transition of the architect's role from ex-nihilo creator to curator of metamorphosis, supporting the hypothesis that contemporary architectural character no longer resides in the imposition of an abstract idea, but in the curatorial intelligence of orchestrating the second life of matter, establishing the finitude of resources as the basis for a new and conscious creative freedom.

2. Mining Protocol and Diagnostics
This dimension of inquiry considers the technical and procedural specifics of Urban Mining operations, investigating the methodologies necessary to transform the existing building from an inert volume into an active resource bank. The analysis initially focuses on preventive mapping and cataloging tools, investigating how the integration of advanced material surveys, the use of Building Information Modeling (BIM) platforms, and the implementation of digital material passports make it possible to precisely census the quality, quantity, and position of recoverable components. These tools do not perform a simple geometric scan, but act as dynamic inventories capable of tracking the maintenance history and chemical-physical characteristics of the elements, providing an indispensable cognitive base to plan an effective and economically sustainable selective deconstruction. The critical core of the section is dedicated to diagnostic procedures employed to attest the residual performance of the waste, a fundamental preparatory step for its re-introduction into the building cycle. The protocol of in situ investigations and laboratory tests (often destructive and non-destructive) aimed at determining mechanical resistance, durability, and the absence of hazardous contaminants is analyzed. Such an investigation is particularly relevant for structural elements, where ensuring the safety of the artifact is an essential condition for overcoming the technical inertia that still burdens recovered materials. It deepens the delicate reclassification process in which the object, legally identified as waste, is elevated to the status of secondary raw material through End of Waste processes.

3. Quantitative Analysis
This dimension of inquiry sets out to transpose the theoretical instances of upcycling inside a framework of numerical and scientific evidence, providing an objective metric to the environmental value of the intervention. The fulcrum of the analysis lies in the quantification of embodied carbon (the sum of all greenhouse gas emissions produced during the extraction, transport, processing, and installation of building materials). Through the application of Life Cycle Assessment (LCA) methodologies, each case study experiences a rigorous comparative balance that relates the impact of the adopted regenerative strategy compared to a reference scenario based on demolition and subsequent construction ex-novo with virgin materials. This quantitative approach illustrates how upcycling can drastically reduce the impact of the construction sector in the initial phases of the building lifecycle (Stages A1–A3), which are the most critical for achieving international climate targets.

4. Economic Analysis
This dimension of inquiry addresses the financial sustainability of the restorative process, intending to demonstrate that upcycling should not be considered an additional burden dictated by purely ethical instances, but a prospective and competitive economic strategy. The analysis performs a systematic and strict comparison between the cash flows of a traditional construction site and those of an intervention based on the metamorphosis of matter. Here, the direct costs of selective deconstruction (inherently higher due to the need for specialized labor and longer dismantling times) are weighed against the savings derived from avoiding the purchase of virgin raw materials and drastically reducing landfill disposal charges. Through the examination of the case studies, it is highlighted how upcycling, if correctly integrated within a structured Urban Mining supply chain, is capable of generating new economies of scale. Furthermore, this section aims to demonstrate that the regenerative practice can increase the real estate value of the asset. Ultimately, the economic analysis validates the hypothesis that the city understood as a material bank represents a capital value reserve: converting every existing building into an opportunity for savings rather than a liability to be torn down allows investments to shift from the destructive extraction phase to the specialized curatorial phase, transforming sustainability from a superficial simulation into a solid pillar of contemporary real estate development.

5. Problems and Successes: The Lesson Learned
In this section, the barriers linked to the management of End of Waste are analyzed, investigating how the legal qualification of waste often represents the primary obstructive obstacle to the metamorphosis of matter, making a potential resource into a paralyzing bureaucratic burden. The section further considers the logistical and technical difficulties arising from the intrinsic fluctuation of recovered matter. The analysis of the case studies shows how the success of the intervention depends on the project team's ability to transform these key issues into creative opportunities, adopting a resilient approach that replaces the rigidity of the plan with the flexibility of the process. Ultimately, the successes achieved and difficulties encountered are synthesized into lessons learned, constituting a solid and indispensable know-how for the future of regenerative architecture.

6. Operational Protocol
Each examination section concludes with the formalization of a synthetic action protocol, intended not as a rigid recipe or a univocal instruction manual, but as a flexible process model. The objective is to extrapolate from the architectural episode a logical sequence of operations, decisions, and technical guidelines characterized by transferability—namely, the capacity to be successfully declined in production and regulatory contexts different from their origin. Comparing the various operational protocols permits the identification of the lowest common denominators of European regenerative architecture, offering legislators and local institutions proof that the valorization of waste is a governable, safe, and codifiable process. The protocol thus becomes the driving force to transform the theory of material metamorphosis into a concrete urban policy, capable of turning the city's dormant industrial heritage into a strategic resource for the ecological transition.

Objectives of the comparison

The academic ambition of this chapter is not exhausted by the simple descriptive cataloging of virtuous architectural episodes, nor by an aesthetic review of environmentally friendly solutions; rather, it aims at an operational synthesis of systemic scope, capable of transforming the analysis of isolated cases into a codified design methodology. The application of a rigorous multiparametric analysis to the selected case studies is aimed at drafting an adaptive intervention protocol, a tool usable by contemporary design practices to manage the complexity of the circular economy.

The objective is to provide a reference framework that remains effective even in urban contexts characterized by regulatory asynchronies or material availabilities profoundly different from those of the excellence geographies analyzed, guaranteeing the transferability of the identified logistical and tectonic principles.

The cross-comparison between these different experiences intends, in the first instance, to dismantle an ideological and cultural prejudice still strongly embedded in the architectural debate: the idea that upcycling is a purely artisanal practice, excessively burdensome in terms of time and costs, or necessarily confined to a niche of experimentation for an elite sensitive to environmental issues. On the contrary, the comparative investigation intends to demonstrate that we are facing a mature industrial strategy, equipped with traceability and certification protocols that make it ready to be scaled up to the metropolitan dimension.

The objective is to demonstrate that upcycling can and must become the new construction standard of urban regeneration, capable of competing with linear production models not only on an ethical level, but also on that of technical efficiency and economic feasibility.

Ultimately, the adopted methodology aims to validate a radical ontological hypothesis that reinterprets the very concept of the building stock: the idea that the existing city is not a set of immutable, finite volumes destined for obsolescence, but an immense dynamic catalog of parts in a state of quiescence, a repository of energy and matter ready to be deconstructed, reclassified, and recomposed into new architectural syntheses. This vision completely overturns the axis of the project and the role of the designer: the creative act no longer resides in the invention of form ex nihilo, but in a refined curatorial capacity. The architect becomes an orchestrator of resources, capable of selecting elements from a widespread urban inventory and designing their second life through a new tectonic rigor.

The comparison of the case studies will therefore serve to define the technical rules of this new assembly, offering empirically based answers on how to manage dimensional tolerances among heterogeneous components, how to design reversible mechanical connections, and how to guarantee performance integration among materials of different matrix and provenance.

The ultimate objective of this analytical effort is to provide realities, such as Turin, with the scientific and technical proof that its vast industrial past and twentieth-century building fabric do not constitute an environmental burden to be disposed of or an economic liability, but a ready, modular, and potentially certifiable material bank.

Through comparison with international models, the thesis intends to show that our cities already possess within their urban deposits the physical capital necessary to generate a season of authentically regenerative architecture, transforming the management of embodied carbon into the most urgent political and design act of our time.

01
(P)RECAST UIA PAVILLON



3XN - GXN
Copenaghen, DK
2023
Size S

02
EUSTON TOWER



3XN - GXN
British Land
London, UK
2023
Size L

03
RESOURCE ROWS



Lendager Group
NREP | AG Group
Copenhagen, DK
2015 - 2019
Size M

04
UPCYCLE STUDIOS



Lendager Group
NREP | AG Group
Copenhagen,DK
2015 - 2018
Size M

05
BLUECITY OFFICES



Superuse Studios
BlueCity
Rotterdam, NL
2017
Size M

06
TANGENKAIA HARBOR



SLA
Tangenkaia Eiendom
Drammen, NO
2020
Size L

07
WATERFRONT NEIGHBOURHOOD



GXN - 3XN
Waterfront Toronto
Toronto, CA
2026
Size L

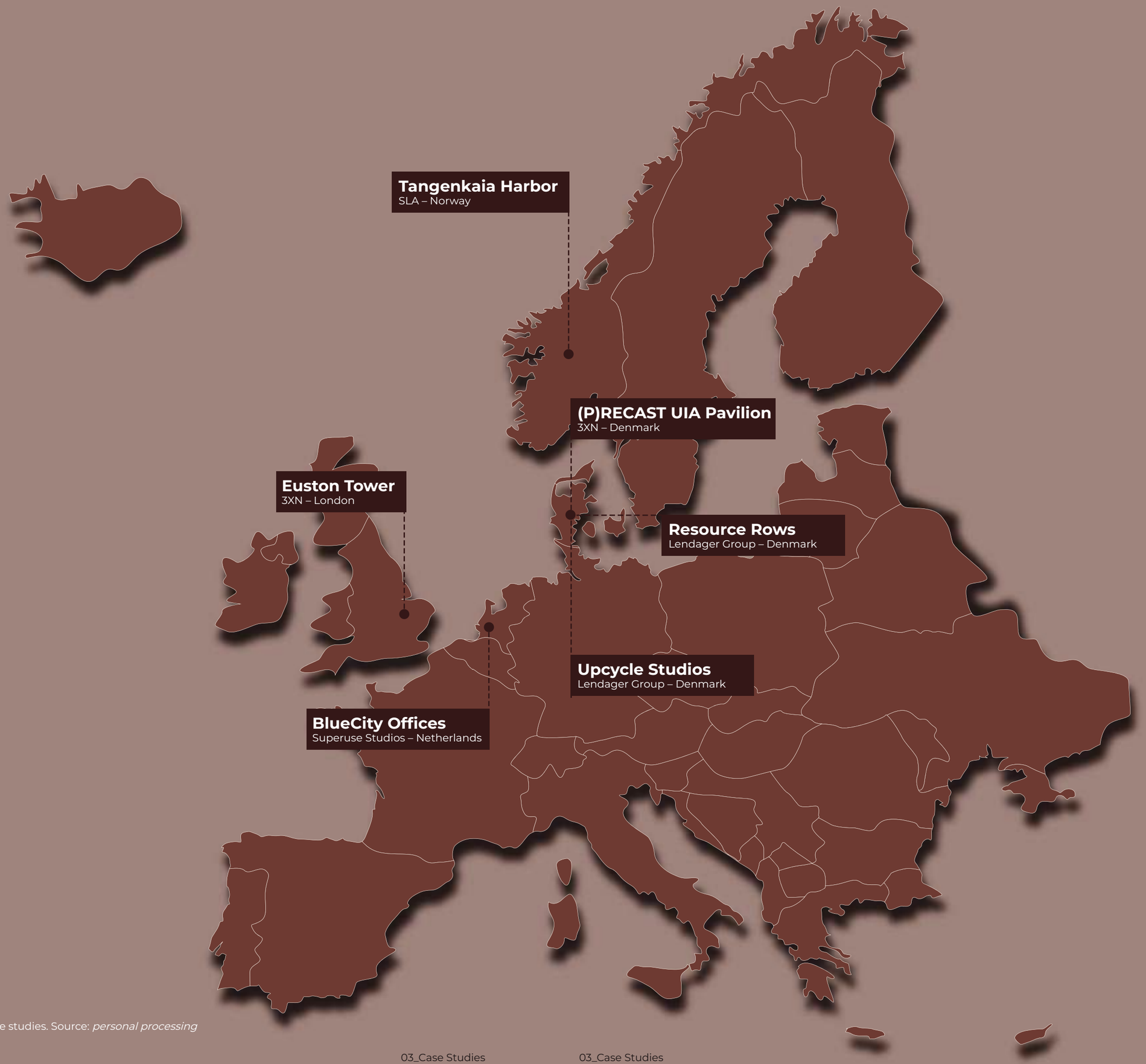


Fig. 25_European map identifying case studies. Source: *personal processing*

(P)RECAST UIA Pavilion

Designer:
3XN - GXN

Site:
Copenaghen, Denmark

Year:
2023

Size S
Pavillon

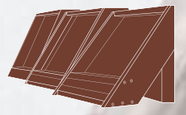


Fig. 26_(P)recast UIA Pavillon - GXN- 3XN, Copenhagen, 2023. Source: *gxn.3xn.com*

The (P)RECAST pavilion, created for the **UIA 2023 World Congress of Architects**, acts as the technical and scientific manifesto for the recovery of the most critical, widespread, and problematic element of the modern construction industry: **precast reinforced concrete.**

The project, the result of collaboration between the 3XN studio, its research arm GXN, and industrial partners in the demolition and cement sectors, aims to dismantle the dogma of concrete's linear life. Historically, this material has been conceived as a monolithic and indivisible entity; once the building's useful life has ended, the only foreseen exit route is impact demolition (crushing). This process, defined as downcycling, degrades a structural element with high embodied energy into a low-value aggregate for road sub-bases, permanently losing the economic and mechanical value of the original form and reinforcement (cf. European Parliament & Council of the European Union, 2008).

(P)RECAST demonstrates instead that it is possible to perform a surgical extraction of matter. In fact, the pavilion was not built with new pours, but is the result of the disassembly of a 1980s office building slated for demolition in Copenhagen. The methodological challenge analyzed here answers three fundamental questions posed by the ecological transition:

• The inversion of the demolition process:
How can the destruction of a building be transformed into a "selective harvesting" of intact components?
The project introduces diamond wire saws and radar scanning techniques to map internal reinforcements before cutting, allowing floors and walls to be separated without damaging their residual load-bearing capacity (Danish Building Regulations, 2022).

• The certification of the existing:
How can an element extracted from an old construction site be integrated into modern structural calculations?
Through carbonation tests and in situ load tests, the research team defined a validation protocol that equates recovered concrete to a newly produced precast product, bypassing regulatory and insurance skepticism (ETA Danmark, 2021).

• Design for Disassembly:
Different from traditional precast elements joined by cementitious completion pours that make separation impossible, the (P)RECAST pavilion utilizes dry mechanical joints. This means the building is not only made of waste, but is itself a material warehouse ready to be disassembled and reassembled into a third or fourth configuration (European Commission, 2020; UK Green Building Council, 2019).

In concerning environmental impact, the collected data are revolutionary: the direct re-use of components enabled a reduction in CO_2 emissions exceeding 80% compared to the production of analogous virgin concrete elements (European Commission, 2019; European Commission, DG Environment).

The pavilion thus becomes clear evidence that concrete, when treated as a **modular system** rather than a formless mass, can become the protagonist of a closed-loop circular economy.

The genesis (data and methodology)

Concrete is responsible for 8% of global CO_2 emissions. Approximately 60% of emissions in cement production do not derive from the energy used, but from an unavoidable chemical reaction: the calcination of limestone (Intergovernmental Panel on Climate Change [IPCC], 2021).

Traditional demolition is, technically, a thermodynamic failure: additional energy is consumed to destroy a material that still possesses 80% of its residual mechanical useful life (Gorgolewski, 2017).

In Italy and Denmark, the standard end-of-life processing of precast elements is impact crushing, but this implies:

1. Technological Degradation: A prestressed beam or hollow-core slab (elements of very high technology and resistance) is reduced to grit (Milad et al., 2025).
2. Loss of Form: The highest environmental cost is not the material itself, but its structural form. Crushing it means losing the work of shaping, reinforcement, and prestressing performed at the factory (McDonough & Braungart, 2002).
3. Inefficient Cycle: The resulting recycled aggregate is used for road sub-bases, while for the new building that will rise in place of the old one, new cement must be produced, fueling an infinite extractive cycle (European Parliament & Council of the European Union, 2008).

The (P)RECAST case introduces the technique of **Preventive Urban Mining**.
The GXN studio collaborated with demolition companies to change the order of operations on-site:

• Structural audit of the bonor Building:
Prior to demolition, the building is "X-rayed." Components with the most standardized geometry and the least signs of surface degradation are selected.

• Reinforcement mapping:
The use of GPR (Ground Penetrating Radar) scanners is essential to see where the reinforcing bars run. This allows decisions to be made on where to cut without severing elements vital to the stability of the individual module (Surgical Selection).

• Extraction vs. Demolition:
The element is harnessed, cold-cut with diamond saws, and extracted intact, keeping its load-bearing properties.

The re-use of an existing element is the only strategy that allows for a drastic reduction in environmental impact while not sacrificing concrete's performance.

• Carbon reduction (70–90%):
These savings stem from the fact that the clinker supply chain, aggregate extraction, and steel reinforcement processing do not need to be activated. The only emissions produced are those linked to transport (zero kilometers or local radius) and electricity for cutting.

• Energy comparison:
Recycling concrete by crushing it consumes approximately 10 times more energy than simply cutting and repositioning the intact component.

Through the (P)RECAST workflow, demolition becomes a low-carbon procurement phase. This approach converts the architect into a selector of components, capable of designing new buildings starting from a catalog of pre-existing pieces, ensuring real sustainability rather than just a decrease in operational energy consumption.

(P)RECAST Protocol

The (P)RECAST pavilion project, developed by GXN in collaboration with the Danish Technological Institute, is one of the most advanced European experiments in the direct re-use of precast concrete structural elements.

To overcome severe regulatory barriers and uncertainties regarding the performance of historic materials, the research consortium integrated the phases of diagnostics, deconstruction, and design into a single cohesive protocol (GXN, 2023 | GXN Technical Report, 2023).

01

3D LiDAR survey and digital mapping

The protocol begins on the donor building (a 1960s elementary school undergoing decommissioning in the Vanløse district of Copenhagen). Prior to any physical intervention, the entire precast panel structure underwent a geometric survey via terrestrial 3D laser scanning (LiDAR).

This operation enabled the digitization of the exact morphology of two specific categories of elements:

· Prestressed hollow-core slabs:
horizontal elements internally lightened by longitudinal channels (cores) and structured with prestressed steel cables in the tensile zone of the pour.

· Reinforced concrete wall panels:
internal load-bearing partition walls distinguished by high material density and critical mass.

The millimeter-scale point cloud allowed for the mapping of geometric deviations, out-of-plumb conditions, and actual deformations sustained by the elements over sixty years of service, thereby overcoming the unreliability of historical archive drawings.

02

Non-destructive diagnostics

Each component has a specific investigation methodology:

· High-Frequency Ground Penetrating Radar (GPR, 1.5–2.6 GHz) on Hollow-Core Slabs:
This electromagnetic technology enabled the internal scanning of the slabs to map the exact trajectory of the prestressed steel strands. Mapping the position of the rebars was important for planning subsequent cutting points and avoiding the severance of primary reinforcement cables, an operation that would have compromised the structural strength of the entire element.

· Pachometry and Phenolphthalein Testing on Solid Wall Panels:
Pachometry measured the concrete cover thickness and the diameter of surface reinforcement. Simultaneously, the phenolphthalein test verified the carbonation penetration depth. The observed carbonation level was lower than the concrete cover thickness, eliminating the latent risk of internal reinforcement corrosion.

· Ultrasonic Integrity Testing:
Performed to verify the absence of internal cracking, honeycombing, or industrial casting voids that could have compromised the panels' resistance once handled.

03

Controlled deconstruction

Physical extraction of components was executed via controlled demolition techniques, strictly prohibiting the use of demolition hammers, which would have transmitted damaging vibrations and induced micro-cracking in the historic concrete:

· Diamond Wire Saws for Hollow-Core Slabs:
The slabs were sectioned orthogonally to the direction of the prestressed strands using water-cooled diamond wire saws. The cutting caused an unavoidable release of steel tension at the panel ends, but preserved the prestressing in the central portion of the elements.

· Dismantling of Solid Walls Along Joints:
The wall panels were isolated by incising the existing cementitious joints that welded them to the structure. To allow the safe lifting of elements lacking active lifting hooks, precision through-holes were drilled at nodal points indicated by structural calculations.

04

Characterization and load testing

To transcend regulatory limits and secure structural homologation, a selection of pilot components was transferred to the laboratories of the Danish Technological Institute:

· Core Drilling on Solid Panels:
Cylindrical specimens were extracted and subsequently subjected to destructive crushing tests in a press. The tests revealed a concrete compressive strength class superior to the earliest 1960s design data.

· Three-Point Bending Load Tests on Slabs:
Cut hollow-core slabs were loaded to failure to monitor cracking behavior and residual ductility, mathematically supporting the load-bearing capacity of the elements slated for re-use.

05 Parametric Optimization

The accurate geometric data obtained from the LiDAR survey and the certified laboratory strengths were integrated into a parametric algorithm (BIM/Grasshopper):

· The static conversion of hollow-core slabs:
To neutralize the loss of prestressing caused by strand cutting, the hollow-core slabs were rotated 90 degrees and positioned vertically within the pavilion, transforming them into load-bearing walls. Working exclusively under compression (the ideal stress state for concrete) the panels no longer needed to rely on their original flexural prestressing.

· The re-use of solid panels as ballasts and counterforts:
Unable to construct excavated or cast-in-place foundations on the temporary pier of Refshaleøen, the heavy solid reinforced concrete panels were laid horizontally on the ground to act as load-distribution plates and dry shallow foundations. Other panels were erected orthogonally to function as counterforts against wind loads.

06 Design for Disassembly

The construction phase synthesized the entire protocol through the design of entirely reversible execution details, avoiding the use of wet mortars or adhesives that would have compromised the future renewability of the components:

· The Toleranced Timber Interface:
The inevitable geometric imperfections arising from the cutting of the concrete panels were absorbed by interposing a subsidiary load-bearing skeleton composed of historic reclaimed timber beams (with a 200-year useful life, salvaged from a warehouse in Østerbro). The wood acted as a flexible joint, “embracing” the concrete and preventing torsional stress concentrations at contact points.

· Mechanical Flanged Joints:
The concrete panels were secured to the timber structure exclusively via galvanized steel plates and bolts. These connections operate through clamping action, exploiting surface friction without requiring additional dowels or holes in the concrete, thereby preserving the component’s integrity for later use.

At the end of the pavilion’s life cycle, this completely mechanical joining system allowed the structure to be dismantled in just a few hours, returning the hollow core floors and solid panels intact and free of chemical contamination, ready to be reinserted into a third permanent construction chain.

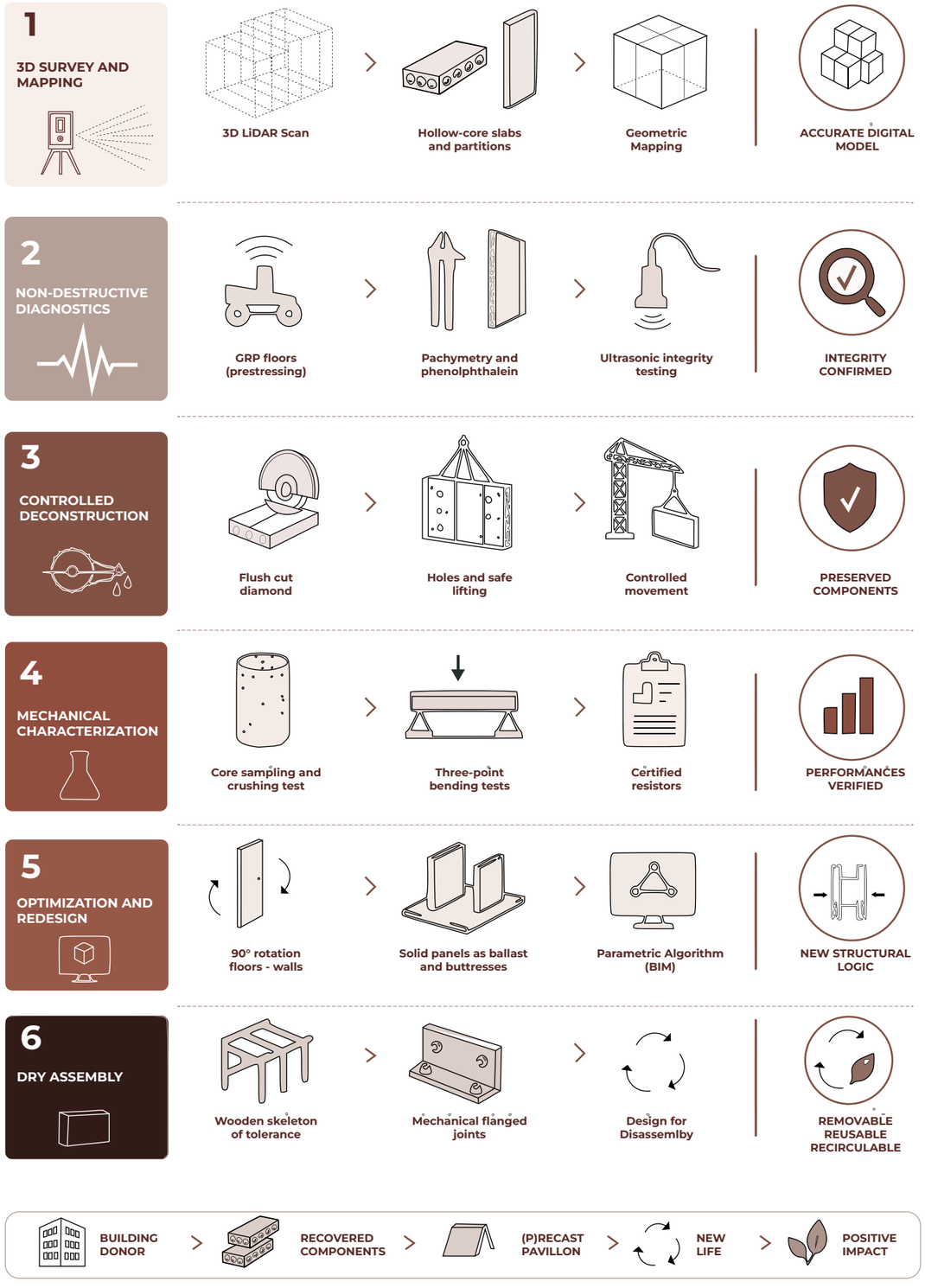


Fig. 27_(P)recast Protocol. Source: *personal processing*

Quantitative analysis

The project validation lies in data measurability, which demonstrates that concrete upcycling is not merely technically feasible, but environmentally and economically superior to traditional construction across every Life Cycle Assessment (LCA) parameter (GXN, 2023).

MATERIAL RECOVERY

GXN's objective was to demonstrate that an entire load-bearing system can be generated without tapping into new extractive resources.

· Maintenance of Function:
100% of the load-bearing structure (vertical walls and horizontal floors) was constructed by reusing elements salvaged from a single office complex slated for demolition.

· Component Integrity:
In contrast to traditional recycling, where concrete is crushed, losing its "structural intelligence" (shape and reinforcement), here 100% of the existing geometry was preserved.

· Saved Mass:
The operation avoided the extraction and transport of approximately 150 tons of virgin aggregates and the use of about 5 tons of reinforcement steel, resources that typically require high-impact extractive processes.

CARBON DATA

The Carbon Footprint parameter is the most striking indicator. A comparison between a virgin precast structure and the (P)RECAST structure reveals an emissions reduction that exceeds European targets for 2050.

· Traditional Structure (Baseline):
An equivalent structure made of newly produced precast concrete emits an average of 45 kg CO_2e/m^2. This figure includes raw material harvesting, clinker calcination (which occurs at 1450°C), and transportation.

· (P)RECAST Structure:
The footprint was calculated at a mere 3.5 kg CO_2e/m^2.

The net savings amount to 92.2%. The only residual emissions are strictly attributable to the electrical energy required for diamond cutting (the mining phase), mechanical lifting, and local transport. In engineering terms, this means the environmental cost of the building was almost entirely paid 40 years ago during its initial construction.

LOGISTICS AND STANDARDIZATION

One of the main obstacles to reusing large precast elements is their weight and out-of-standard dimensions. SLA and GXN resolved this issue through logistical modulation.

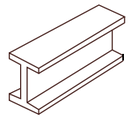
1. Sectioning for Mobility
The first panels of the donor building were too large for optimised urban logistics. Through surgical cutting, they were reduced into standardised modules.

2. Load Saturation
The size of the modules was calculated to saturate the loading deck of standard articulated lorries (13.6 meters). This reduced the number of trips by 30% compared to transporting unsectioned pieces and operated without the need for exceptional transport, which is highly costly and disruptive to traffic.

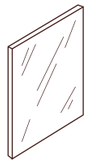
3. Simplified Construction Sites
The use of weight-controlled modules allowed for the deployment of medium-capacity cranes. This makes the assembly technology available even to medium-sized construction firms, a key factor in the model's scalability in dense urban contexts such as those of Italian cities.

Quantitative estimate

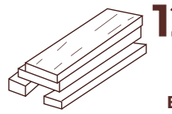
Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



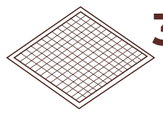
56 BEAMS STEEL
BEFORE: Former warehouse
AFTER: Primary structure



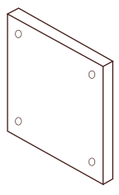
84 PANELS GLASS
BEFORE: Former office building
AFTER: Closures



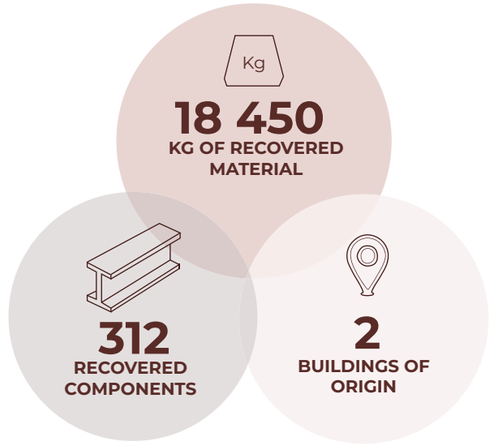
120 SLATS WOOD
BEFORE: Former platform
AFTER: Finishing and furnishings

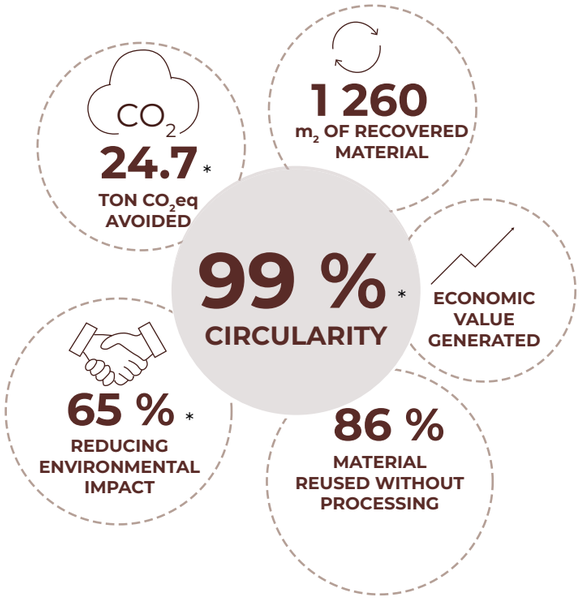


32 GRATINGS METAL
BEFORE: Former footbridge
AFTER: Paving



20 PANELS CONCRETE





* Value estimated via AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 28_Quantitative analysis (P)recast. Source: *personal processing*

Economic analysis

The economic analysis of the (P)RECAST project demonstrates a shift in the financial center of gravity: capital is no longer spent on the purchase of matter, but on the management of information and logistics. In a traditional construction site, material is a commodity with a certain price; in structural upcycling, material is an unknown that must be transformed into an asset through diagnostics (GXN, 2023).

AVOIDED COSTS

In a structural upcycling operation, savings are not simply the absence of a purchase cost, but the elimination of exit liabilities burdening the donor building. This creates an industrial symbiosis between those who demolish and those who construct.

1. Raw material at zero cost:
The savings on the purchase of virgin precast concrete are total. In a global market defined by the instability of raw material rates and energy costs (clinker requires temperatures of 1450°C), having an existing structural inventory buffers the project budget against inflation.

2. Elimination of the Landfill Tax:
Disposing of reinforced concrete in landfills entails high weight-based taxes and disposal fees. The (P)RECAST protocol transforms an economic liability (the disposal cost for the owner of building A) into a resource for the owner of building B. Going forward, those who build via upcycling could be paid to retrieve materials, completely reversing the value chain.

EXTRA COSTS

Upcycling shifts spending toward the pre-design and structural validation phases. These costs are necessary to make the recovered element bankable and insurable.

• Survey and testing (+40%):
Validating an existing component entails notable supplementary economic effort. Chemical analyses (carbonation, chlorides), GPR surveys, and in situ load tests have a noticeable impact. This extra cost is the equivalent of the “factory warranty” for new items. Without this dataset, the element has no legal value and cannot be included in an official structural calculation.

• The logistical and storage challenge:
This is the critical point identified by GXN:
o Temporal asynchrony: It is extremely rare for the demolition phase to coincide with construction.
o Need for hubs: Elements require intermediate storage spaces, cleaning, and minor restorations.

TOWARDS COST PARITY (2030)

Currently, the overall cost of a (P)RECAST operation is estimated to be between 10% and 15% higher than new construction. However, this analysis does not account for three impending macroeconomic factors that will make upcycling the most economical choice within a few years:

1. Industrialization of the supply chain:
Today, every reuse project is a prototype. With the emergence of specialized operators (Deconstruction Managers) and digital warehouses, testing and logistics costs will drop by 25–30% due to economies of scale.

2. Carbon Tax and ETS (Emission Trading System):
Introducing severe taxes on embodied CO_2 will make virgin cement a luxury good. If the cost of the saved carbon (Carbon Credit) is included in the economic calculation, upcycling is already more affordable than new construction today.

3. ESG Ratings and Green Finance:
Buildings constructed with recovered materials achieve certifications (LEED, BREEAM) that facilitate access to preferential-rate mortgages and attract institutional investors, amply compensating for the on-site extra cost with a lower cost of capital.

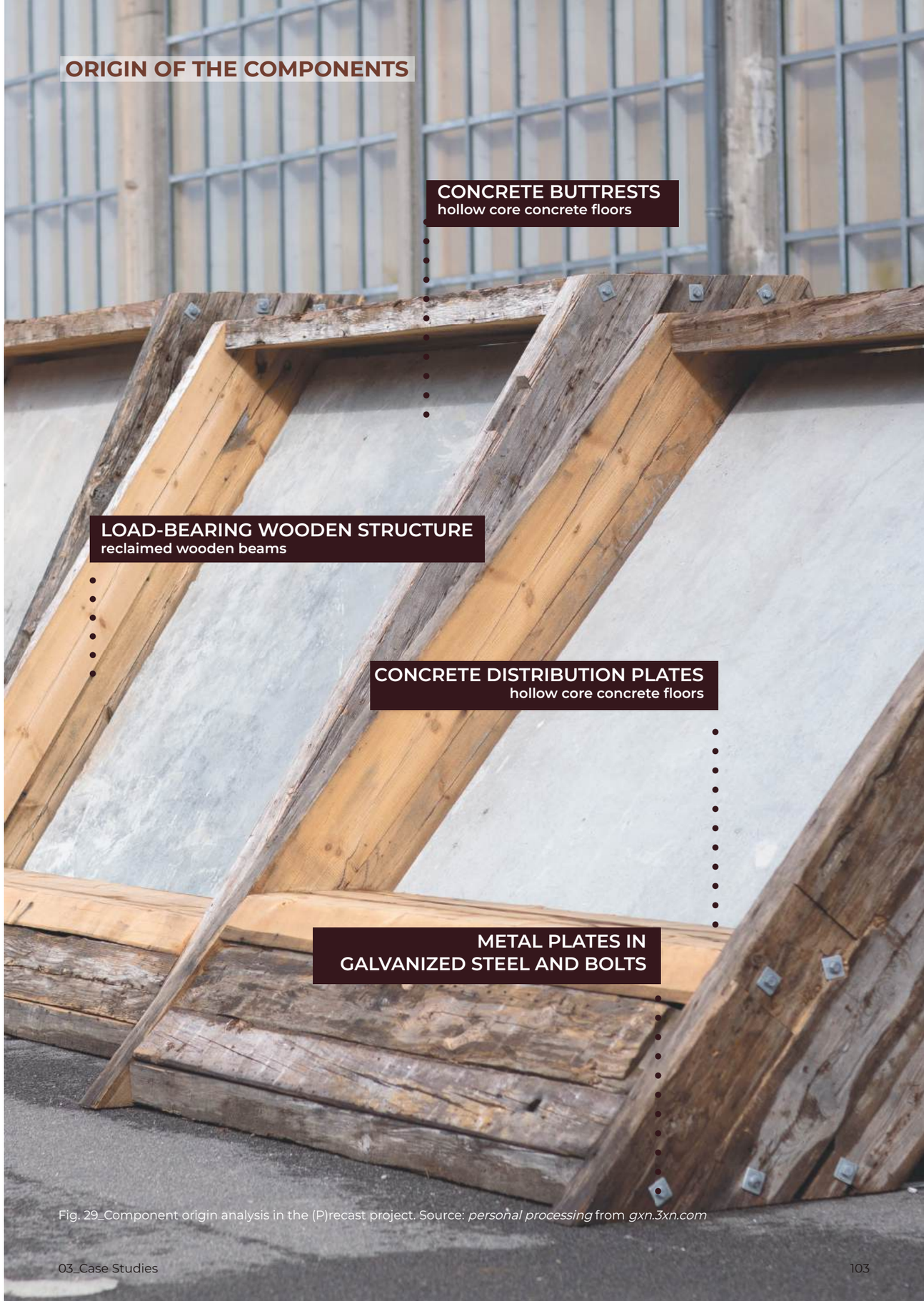


Fig. 29_Component origin analysis in the (P)recast project. Source: *personal processing* from *gxn.3xn.com*

Problems and Successes: Lesson Learned

The experience of the (P)RECAST pavilion made it possible to map the friction between the rigid engineering of the past and the flexibility demanded by the contemporary circular economy.

The Technical Problem: The Legacy of "Wet Joints" and Monolithicity
The primary structural obstacle encountered by 3XN/GXN lies in the construction philosophy of the 1970s and 1980s. During that period, precast construction aimed to emulate cast-in-place behavior through the monolithicity of its junctions.

· The constraint of the "wet joint":
Panels were joined using protruding reinforcements that were interlaced and subsequently embedded in cast-in-place completion pours. Once cured, these nodes render the components a single unified body.

· The barrier to circularity:
To separate two panels joined by a concrete pour, standard practice requires destroying the node using hydraulic hammers. This process is inherently destructive: vibrations and impacts damage the ends of structural components, making immediate re-use impossible without costly restoration work or a downgrading of load-bearing capacity.

The Solution: Dry Mechanical Joints
To overcome the obsolescence of wet joints, GXN developed a system of reversible connections that transforms concrete from a static mass into a modular system.

· Bolted connections (Dry Joints):
The modules extracted surgically (maintaining a portion of the existing reinforcement or creating new fixing points) were reassembled using interface steel plates and high-strength bolts.

· Reversibility:
This solution totally eliminates the use of structural sealing mortars or cements. As a result, the (P)RECAST pavilion is not a work destined for a single site. It can be dismantled in a few days, transported, and reassembled in a different configuration.

The Aesthetic Success: The Ontology of Matter and the Value of Imperfection
One of the most significant achievements proved to be overcoming the aesthetic prejudice against second-hand concrete. Commonly viewed as a degraded material to be concealed, in the (P)RECAST project it became an element of narrative value.

· Aesthetics of sincerity:
The signs of time (traces of old piping imprinted on the surface, oxidation patinas, original fixing holes, and the traces of diamond cutting) were left exposed. These parts were not treated as defects, but as testimonies to the building's previous lifecycle (the donor building).

· Client appreciation:
The public client rewarded this raw aesthetic. Recovered concrete imparts an architectural soul and historical identity that new, aseptic, and standardized precast units do not possess.

This demonstrates that upcycling can generate a new architectural language that visually communicates environmental commitment, transforming the ethics of reuse into a desirable aesthetic.

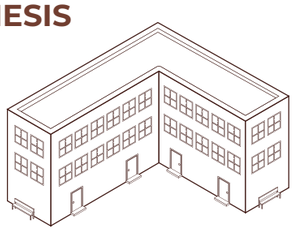




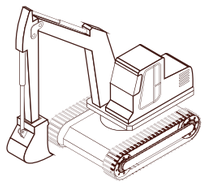


Fig. 30_Photographs of the (P)recast project construction site. Source: *gxn.3xn.com*

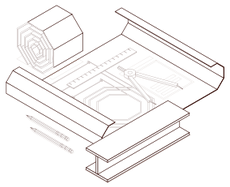
SYNTHESIS



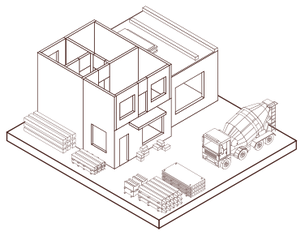
EXISTING BUILDING



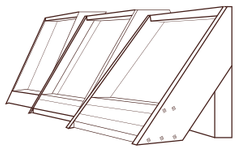
URBAN MINING



DIAGNOSTICS



DESIGN FOR DISASSEMBLY



(P)RECAST PAVILLON

-24.7 t *
CO_2 eq. avoided

-54 % *
total cost

-92 % *
waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 31_Summary diagram of the (P)recast project. Source: *personal processing*



Fig. 32_(P)recast UIA Pavillon. Source: *gxn.3xn.com*

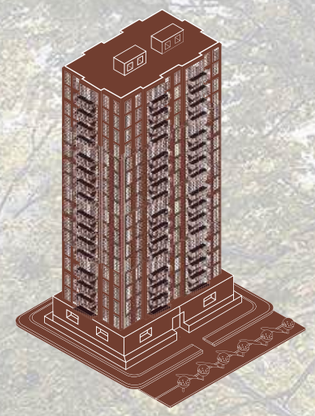
Euston Tower

Designer:
3XN - GXN

Client:
British Land

Site:
London, United Kingdom (77 754 m²)

Year:
2023 - on going



Size L

Urban context |
Large-scale building

Fig. 33_Euston Tower - GXN- 3XN, London, 2023. Source: *gxn.3xn.com*

Euston Tower, a 36-story monolith completed in 1970 and designed by Sidney Kaye, Eric Firmin & Partners, has remained a visual reference point in the London skyline for over half a century. However, like much of Europe's modernist building stock, the tower has reached a key turning point: the energy inefficiency of its envelope and the inadequacy of its internal spaces compared to modern working standards have decreed its commercial obsolescence (Plevoets & Van Cleempoel, 2019). In an aggressive real estate market like London's, the conventional response would have been total demolition: a rapid process that frees up the plot and allows for rebuilding from scratch according to current parameters (Gorgolewski, 2017).

The project by 3XN and GXN, commissioned by British Land, instead takes the opposite path, transforming the building into a monument-scale reverse engineering experiment (GXN, 2023). The primary challenge rested in the client's request to double the property's useful floor area (growing from approximately 30.000 m^2 to over 60.000 m^2).

In a densely infrastructured site like Euston Road, located directly above vital London Underground lines, excavating new foundations to support a building of double the volume would have entailed extreme engineering risks, unsustainable logistical costs, and protracted bureaucratic timelines. By using techniques to lighten the existing structure and grafting cantilevered side volumes, the studio demonstrated that it is possible to double density without touching the ground (Conejos et al., 2014).

GXN's innovation consists in treating the 1970s building as a Material Bank (Ellen MacArthur Foundation, 2013). Rather than emitting new CO_2 to produce virgin steel, the project takes advantage of the residual load-bearing capacity of the existing tower (World Green Building Council, 2019). This allowed the intervention to comply with the strict parameters of the London Plan, which rewards low-carbon projects with accelerated approval processes.

Reverse engineering was applied through a protocol of material interrogation:

• Analysis of structural memory:
Through chemical and physical specimens, the history of the steel rolled fifty years ago was reconstructed, certifying that its mechanical properties remain intact and, in many cases, superior to current legal minimums thanks to the conservative safety coefficients of that era (British Standards Institution, 2013).

• Surgical decomposition:
The building was stripped of its skin and internal organs, leaving only the essential skeleton. This act of selective deconstruction eliminated inefficiency (the old energy-wasting envelope) whilst preserving the primary asset (the load-bearing frame) (Danish Building Regulations, 2022).

To summarize, the introduction to the Euston Tower case lays the basis for demonstrating that upcycling is not a restriction of design freedom, but a multiplication of opportunities.

The project no longer asks:
"What do we want to build?"

Instead, it asks:
"What can we turn what is already here into?"

Euston Tower thus ceases to be an artifact of the past and becomes the prototype of the "Minable City," in which every cubic meter of existing concrete is a precious resource that we can no longer afford to waste.

The genesis (data and methodology)

The Euston Tower project was not conceived as an aesthetic restoration operation, but as an engineering response to an impassable regulatory constraint. For British Land, the cost of carbon became a financial parameter just as critical as the cost of land or materials (GXN, 2023).

• WLC as a Design Constraint
In London, the Greater London Authority (GLA) mandates that every large-scale project justify its carbon footprint across its entire lifecycle (WLCCA) (European Commission, 2019). Demolishing the tower would have instantly released 15,000 tons of embodied CO_2 (Intergovernmental Panel on Climate Change, 2021). Compensating for such emissions with a new building would have required an investment in green technologies so high as to render the project economically unviable.

GXN's methodology demonstrated that by retaining the core and foundations, the saved carbon budget could be reinvested to add new floors and lateral volumes.

• Point Cloud to BIM Methodology
The studio did not rely on 1970 technical drawings. The entire tower was scanned to produce a point cloud that revealed structural deformations, millimeter-scale settlements, and the actual position of the reinforcement within the concrete.
Before drawing a single line of the new design, an "As-Built" BIM model was created. This allowed the team to simulate the tower's reaction under new loads and identify where the existing structure possessed "dormant" residual load-bearing capacity.

• Concrete Engineering
One of the most innovative aspects involves the treatment of structural concrete. To lighten the tower and create new vertical connections, large portions of the existing slabs were removed. Instead of using pneumatic hammers (which would have caused vibrations harmful to the frame), diamond wire saws were employed.

The extracted concrete blocks (often measuring 4.5 m x 1.2 m) were analyzed for compressive strength and carbonation. It was discovered that the 1970s concrete, protected by the curtain walls, exhibited performance levels superior to those originally declared. These items did not become rubble (downcycling); instead, they were cataloged as construction products. Many of these blocks were re-machined to serve as high-resistance paving for the surrounding public plazas or as ballast elements for the tower's new rooftop gardens.

• Timeline and Logistics
During the 18-month investigation phase, the studio executed over 500 core drills and spectrographic tests on the steel, validated the foundations' capacity to support a doubled load through the use of ultra-light materials (timber and recycled steel) in the additional sections, and secured pre-clearance from insurance companies based on empirical data rather than theoretical assumptions.

Furthermore, the old steel beams lacked the penetrations required for modern ventilation ductwork, which is bulkier than in 1970. Rather than drilling through the existing steel and risking stability, GXN designed a perimeter and exposed MEP distribution system, transforming a technical constraint into a prestigious industrial design. In this way, retaining the central core averted the risk of underground instability, given that the Northern Line underground tube runs just meters away from the foundations.

Euston Tower demonstrates that executing a project of this nature requires starting from the awareness that existing matter is already a financed asset. The time spent on the audit (18 months) is amply recovered through accelerated regulatory approval speeds and savings on raw material procurement.

Euston Tower Protocol

The regeneration project of the Euston Tower in London transposes this approach to the complex scale of the skyscraper. The intervention thus defines a new methodological benchmark for deep decarbonization, envelope conservation, and structural preservation within consolidated urban fabrics.

Rather than proceeding with total demolition, the design team developed an approach intended to maximize the in situ conservation of the existing structure and scientifically map the removed portions (GXN, 2023).

01

Diagnostic survey and selective preservation

The first phase of the operational protocol focused on the forensic characterization of the existing structure:

· Diagnostics and Integrated Modeling:
Through the synergistic use of ultra-high-resolution terrestrial 3D laser scanning (LiDAR) and an extensive campaign of non-destructive (NDT) and semi-destructive tests, the designers investigated the conservation state of the reinforced concrete central core, the basement levels, and the deep pile foundations. This digital mapping made it possible to verify the absence of severe degenerative phenomena and to calculate the residual load-bearing capacity of the elements.

· Targeted Conservation and Impact Reduction:
Diagnostic tests showed that 31% of the original structure by volume possessed excellent mechanical performance, fully compliant with up-to-date safety standards. Keeping the vertical core, foundations, and entire underground basement intact eliminated the massive embodied carbon emissions associated with producing, transporting, and pouring new concrete for the building's largest parts.

02

Concrete Extraction Protocol

For the slab portions that could not be conserved in situ, GXN initiated an experimental protocol aimed at treating the cast-in-place concrete as if it were composed of precast elements.

· High-Precision Cutting and Deconstruction:
Large floor slab portions were isolated and sectioned using diamond wire and chain saw technologies. This particular deconstruction technique allowed structural blocks to be removed while preserving their structural strength, avoiding the internal micro-cracking typical of traditional percussion demolition and precluding the production of on-site dust and debris.

· Structural Testing (University of Surrey):
The extracted slabs underwent a stringent validation protocol at the academic laboratories of the University of Surrey. It was demonstrated that the recovered components possess mechanical properties entirely equivalent to those of a newly produced precast product.

03

Soft stripping and recovery of non-structural elements

Before launching the most invasive structural works, the building underwent a careful soft stripping operation to preserve the substantial non-structural material capital present throughout the 32 floors.

· Mapping and Selective Removal:
Internal finishes, ceilings, lighting fixtures, internal window frames, and mobile partitions were inventoried and removed manually or using non-invasive techniques. This cataloging work separated material streams before they could mix into a single unsorted waste stream.

· Redeployment via the EME Platform:
Each extracted component was entered into the digital platform EME (Excess Materials Exchange). This tool facilitated the donation, reuse, or sale of these items to local supply chains and neighboring construction sites, decreasing waste volumes otherwise destined for landfill disposal and promoting a local supply chain based on the second-hand economy and active reuse.

04

Chemical analysis and closed-loop industrial upcycling

The original 1970s 1970s curtain wall facade did not meet contemporary regulatory requirements, making direct reuse impossible without radical replacement interventions.

· Crushing and Spectrometric Analysis:
Significant portions of the original glazed modules were carefully removed and cataloged. The glass was subsequently crushed into cullet (glass scrap) and subjected to advanced spectrometric analyses in the laboratories of partner industrial producers to precisely trace its chemical composition and the absolute absence of contaminants.

· Regeneration into High-Performance Paneling:
Research demonstrated that three of the four types of glass present in the historic facade were suitable for direct re-introduction into industrial melting furnaces. The process enabled closed-loop upcycling: old glass was regenerated into high-performance latest-generation panes, drastically reducing both the consumption of virgin raw materials (such as silica sand) and the thermal energy required for melting in industrial furnaces.

05 Reconditioning and recycling of metals

Alongside glass and concrete, the project paid special attention to secondary structural metal components and building services that were still structurally intact but needed a new functional life.

· Treatment of Metal Profiles:
Steel and aluminum profiles recovered from the disassembled facade and internal support structures underwent strict non-destructive testing to verify the absence of fatigue or plastic deformations. They were then cleaned, sandblasted, and, where necessary, reworked for redeployment as secondary frames or structural reinforcement elements in the new architectural layout.

· MEP Overhaul and Reconditioning:
Recoverable parts of the existing systems (such as high-end electrical components, ventilation elements, or technical metal frames) underwent a rigorous remanufacturing process, testing their electrical and mechanical compliance to allow for a second operational life within the building's new MEP concept or in neighboring tertiary buildings.

06 Material Passports and material traceability

To transform this experimentation into a scalable, economically sustainable fabrication process (surmounting regulatory voids and insurance market resistance regarding recovered materials) the project introduced an advanced, integrated digital management system.

· Material Passports:
Every recovered element (whether a precast concrete slab, a recycled glass module, a metal profile, or an internal component) was censured and equipped with a digital material passport embedded directly into the building's BIM model. This document tracks the component's exact chemical composition, diagnostic history, verified mechanical performance, and detailed instructions for its future disassembly.

· Building as a Material Bank:
Thanks to this continuous, transparent monitoring, the Euston Tower is coded and managed no longer as a static artifact destined for a linear cycle, but as a transitional material bank (Buildings as Material Banks), entirely ready to be deconstructed, tracked, and effectively reused at the end of its future useful lifecycle.

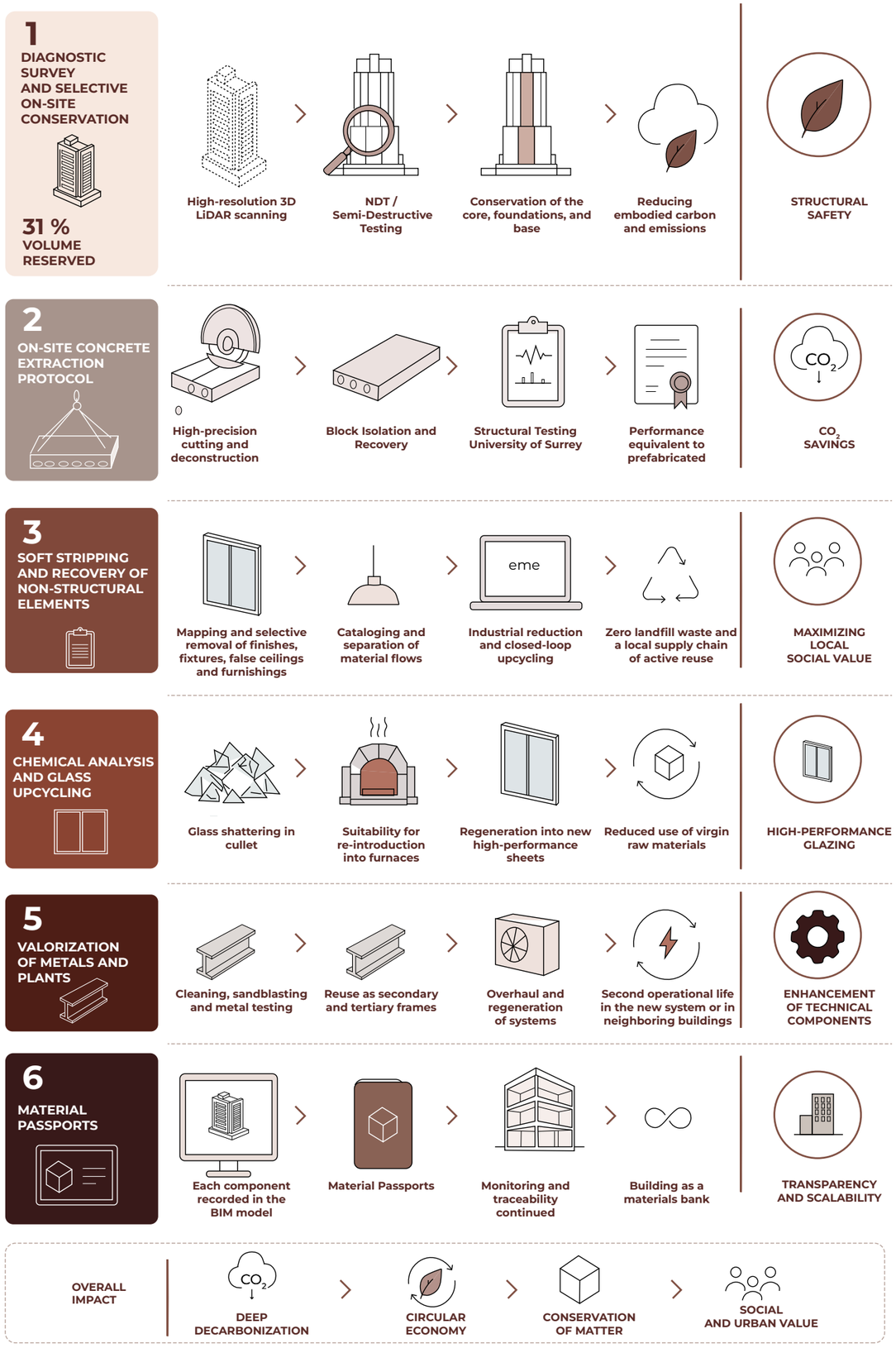


Fig. 34_Euston Tower Protocol. Source: *personal processing*

Quantitative analysis

The analysis of real data provided by the technical reports of 3XN/GXN and Arup reveals how Euston Tower was managed as an operation of capital optimization (both material and financial). In a context of extreme land scarcity and regulatory constraints comparable to London's, success is assessed not only in saved CO_2, but in the ability to generate new usable floor area (GFA) through leveraging the structural inertia of the existing building (GXN, 2023 | Arup & GXN, 2023).

The Foundation System

Retaining 100% of the original foundations was the element that guaranteed the economic sustainability of the entire operation.

· Technical and geotechnical data:
The tower rests on a massive foundation raft and deep piles embedded in the London Clay. Excavating new foundations in a dense area like Euston Road would have entailed extreme engineering risks caused by the millimeter proximity to the London Underground lines (Victoria and Northern lines).

· Avoided costs:
By avoiding new excavations, the risk of differential settlement in neighboring historic buildings was eliminated, and the need to manage groundwater dewatering was removed. In a traditional London construction site, these costs can account for 15–20% of the total construction budget.

· Load efficiency:
Through reverse engineering, it was demonstrated that the existing foundations could support the tower's increased height simply by replacing the heavy old slabs with lighter, modern timber or composite systems.

The Core and the Frame

Retaining 100% of the reinforced concrete central core and 31% of the steel frame forms the linchpin of the project.

· The function of the core:
The existing core was validated to withstand wind loads and seismic forces even for the new, expanded configuration. This avoided months of high-altitude concrete pours, reducing construction noise and dust, a vital aspect for gaining the approval of neighborhood residents.

· The frame as a hub:
The 31% of the retained steel frame wasn't merely preserved, but re-habited. This skeleton served as a logistical platform upon which to graft the new lateral "wings." The savings lie not only in the material, but in assembly time, which was reduced by approximately 25% compared to an entirely new frame.

Embodied Carbon

In London, CO_2 is no longer an abstract metric, but an urban planning negotiation lever.

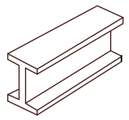
· Negotiation with the Camden Council:
Without the scientific proof (via WLCCA) of saving these 15,000 tons, the council would never have granted the doubling of the volume. In practice, the saved CO_2 was traded for the permit to build more square meters.

· Carbon intensity:
The project achieves a value of 703 kg CO_2e/m^2, beating the most ambitious RIBA and LETI 2030 targets. This figure certifies the building as a future-proof asset, shielding it from upcoming European carbon taxes.

· Impact equivalency:
To give a concrete scale: 15,000 tons of CO_2 is equivalent to not producing about 10,000 tons of virgin steel, whilst avoiding over 4,000 heavy-vehicle trips through congested central London.

Quantitative estimate

Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



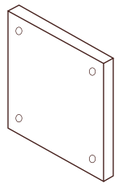
1 200 BEAM STEEL

BEFORE: Former metal structures
AFTER: Primary and secondary structures



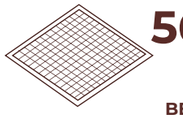
2 800 m² GLASS

BEFORE: Former perimeter facades
AFTER: Facades and internal partitions



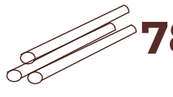
3 100 PANELS CONCRETE

BEFORE: Former attics and floors
AFTER: Non-structural elements

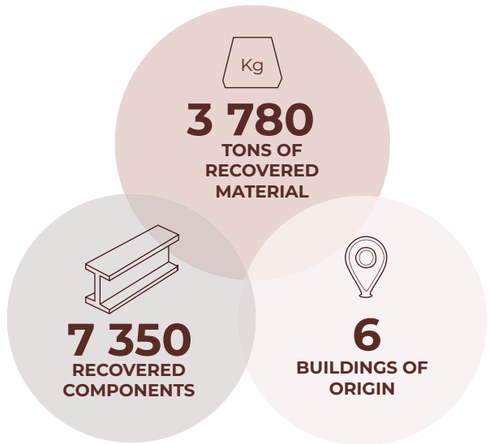


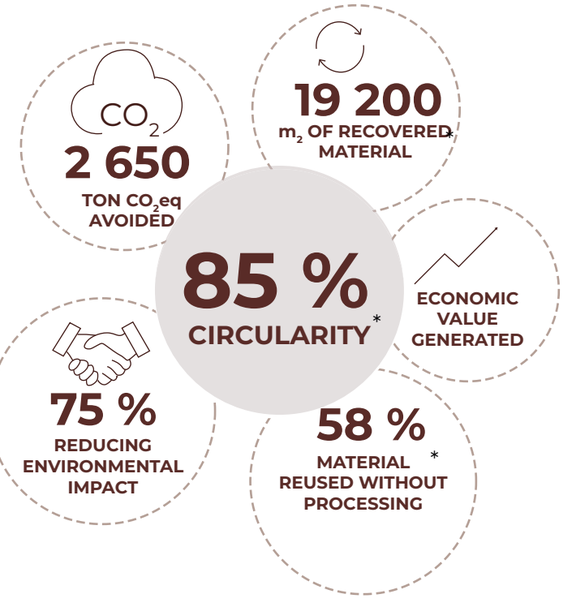
560 GRATINGS METAL

BEFORE: Former suspended ceilings
AFTER: Suspended ceilings and interior partitions



780 ALUMINUM PROFILES





* Value estimated via AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 35_Quantitative analysis of Euston Tower. Source: personal processing

Economic analysis

The economic analysis of Euston Tower shatters the prejudice that structural upcycling is a conceptual exercise more expensive than new construction. Although direct labor costs are higher, the overall balance sheet (Capex and Opex) shows superior profitability thanks to risk mitigation and the creation of a high-ecological-value asset (GXN, 2023 | Arup & GXN, 2023).

Avoided Costs

Savings are not simply the absence of spending, but the elimination of environmental and logistical-related liabilities.

· Raw material and price volatility protection:
Saving on the purchase of approximately 10,000 tons of steel is beyond a saving on the list price. In an unstable global market, having the raw material already on-site eliminates the risk of price changes and supply chain delays. Furthermore, avoiding new massive pours for foundations means saving not only on material, but on the energy and chemical costs of the additives required for such large-scale pours.

· Urban logistics and social costs:
A traditional demolition would have required roughly 25,000 heavy-vehicle trips through the heart of London.

· Landfill Tax:
In the United Kingdom, the Landfill Tax on debris is extremely burdensome (£103/ton). Avoiding landfill disposal of a large portion of the structural volume generated direct savings that cover approximately 60% of the initial diagnostics and testing costs.

Additional Costs (Extra-costs)

The budget shifts from “matter” to “knowledge.” This is where the design studio must justify its fee.

1. Specialized engineering (Up-front Costs):
Fees for material testing, Scan-to-BIM modeling, and Reclaim Manager coordination account for roughly 4–6% of the total budget, compared to 1% for a standard project. This cost is an investment in de-risking.

2. Specialized labor for deconstruction:
Surgical dismantling is slower than demolition. It requires teams specialized in diamond wire cutting and modular decomposition. This entails an increase in labor costs during the “white site” phase (strip-out) of approximately 30–35%.

3. Insurance and certifications:
Insurance companies typically apply higher premiums for recycled materials. Euston Tower overcame this obstacle by providing a digital dataset (Material Passport) so detailed that it equated the warranty of the old steel to that of a virgin product, bringing premiums back to competitive levels.

The Value of the “Future-Proof” Asset

Why, then, does a client like British Land choose upcycling?
The answer lies in the final value of the property (Asset Value):

· Time-to-Market:
Thanks to the CO_2 savings, the project secured planning permits in record time. Entering the rental market 12–18 months ahead of the competition generates a cash return that neutralizes any design extra costs.

· Regulatory resilience:
A building compliant with future carbon taxes has a higher resale value. Energy-guzzling or high-carbon buildings will soon become Stranded Assets; Euston Tower, by contrast, is a certified asset for the next 60 years.

· Access to credit:
The extremely high Environmental, Social, and Governance (ESG) rating allows the client to access Green Bonds and preferential-rate financing, reducing the overall financial costs of the operation.



Fig. 36_Analysis of the origin of components in the Euston Tower project. Source: *personal processing* from *gxn.gxn.com*

Problems and Successes: Lesson Learned

The Major Problem: Regulatory Gap and Fire Safety

The primary technical and bureaucratic obstacle encountered was compliance with modern Fire Safety standards. In the United Kingdom, following tragic events and the subsequent Building Safety Act, regulations for high-rise buildings have become drastically more stringent than those in force in 1970 (GXN, 2023).

The original set of steel beams did not possess the fire resistance ratings (R120 or R180) required for a building of such height and planned use.

Instead of relying on prescriptive solutions (adding more material), the studio opted for a performance-based design approach:

- Active systems engineering:
An upgraded sprinkler system with intelligent point-to-point monitoring was implemented.

- Nanotechnological intumescent paints:
Next-generation, ultra-thin intumescent coatings were used. These react to heat by expanding while leaving the beam section visible under normal conditions.

- Digital validation (CFD):
Safety was certified through high-level Computational Fluid Dynamics (CFD) simulations that modeled smoke and heat propagation, demonstrating to the competent authorities that the hybrid system guaranteed superior safety compared to a standard new building.

Commercial Success: The Metamorphosis into a "Lab-Enabled Building"

The most significant success of Euston Tower lies in proving that upcycling can enhance a building's utility value, elevating it to performance standards superior to the original design.

The challenge was adapting the tower to house scientific laboratories (Life Sciences), which require higher load capacities. This resulted in a 40% increase in rental price per square meter. The real estate market rewarded the character of the recovered building, preferring it over aseptic new constructions, and valued the operation's exceptionally high ESG rating.

Towards Reversible Architecture

The issue encountered with system integration (the old beams could not be drilled for the passage of modern, bulkier ductwork) taught a fundamental lesson on temporal flexibility:

1. Exposed services and maintainability:
The studio had to design MEP routing external to the structure, turning a technical limitation into an architectural language choice. This ensures that in 20 years, systems can be upgraded without demolishing any structural parts.

2. Design for Disassembly (DfD):
Today, Euston Tower is not only made of reclaimed materials, but is itself designed to be dismantled. Every newly added component (facades, modular walls, mechanical connections) has been cataloged in the Material Passport.

3. The paradigm shift:
The building has become an evolving platform. This approach roots out the problem of future construction waste: 50 years from now, Euston Tower will not be demolished, but harvested and redistributed into new production cycles.

The economic success (the +40% rent increase) proves that sustainability isn't a sacrifice, but a value multiplier.



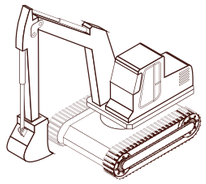


Fig. 37_Photographs of the Euston Tower construction site. Source: *gxn.3xn.com*

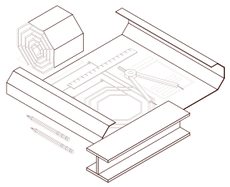
SYNTHESIS



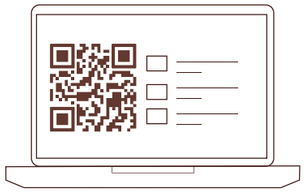
EXISTING BUILDINGS IN EUSTON AREA



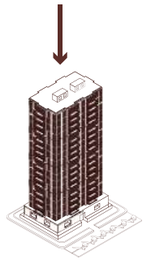
URBAN MINING



DIAGNOSTICS



MATERIAL PASSPORT



EUSTON TOWER

-2 650 t *

CO_2 eq. avoided

-38 % *

total cost

-58 % *

waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 38_Euston Tower project summary diagram. Source: *personal processing*

Fig. 39_Euston Tower. Source: *gxn.3xn.com*.

Resource Rows

Designer:
Lendager Group

Client:
NREP | AG Group

Site:
Copenhagen, Denmark(9 148 m²)

Year:
2015 - 2019

Size M
Single building

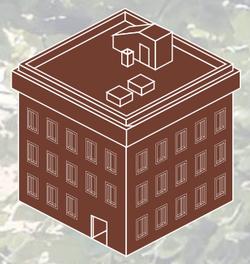


Fig. 40_Resource Rows - Lendager Group, Copenhagen, 2019. Source: *lendager.com - Rasmus Hjortshøj*

The Resource Rows (Ressourcerækkerne) residential complex, a mixed architectural entity of approximately 9,000 square meters completed in 2020 within the rapidly expanding district of Ørestad Syd in Copenhagen, operates within one of the most dynamic yet controversial real estate development laboratories in contemporary Scandinavian planning.

Unlike stratified historical urban fabrics, this new sector suffered from a strong intrinsic methodological obsolescence: conceived according to the logic of standardized mass real estate speculation, the district continued to replicate linear construction models based on the uncritical assembly of virgin, freshly extruded industrial components, resulting in a massive environmental impact in terms of embodied carbon. In an aggressive real estate market driven by speed of execution, the conventional response to satisfy strong housing demand would have been the use of homologated, cataloged construction packages, a standardized linear process that optimizes short-term profits while ignoring the systemic crisis of material resources.

The project by the Lendager Group, commissioned by the real estate investment fund NREP in collaboration with engineering firm MOE (now Artelia), instead takes the opposite path, transforming a mass multi-family residential program into an experiment in industrial ecology and reverse engineering applied to the scale of the building component.

The primary challenge stayed in the client's explicit demand to prove the feasibility of a radical circular approach within a framework of absolute **cost neutrality** and marketing speed compared to linear competitors in the same district. This broke the prejudice that relegates upcycling to a purely artisanal, elite practice confined to small scales (Szaky, 2014).

Using innovative modular prefabrication techniques and entirely dry connection elements, the studio proved that it is possible to achieve the highest standards of energy efficiency and structural stability without extracting new raw materials from the biosphere, simply by intercepting the region's environmental liabilities.

This positioned the intervention within the strict parameters of Scandinavian energy requirements (BR18), anticipating future limits on embodied emissions and guaranteeing a 29% net reduction in the total lifecycle carbon footprint of the building organism (Danish Building Regulations, 2022; World Green Building Council, 2019).

The **Design by Availability** method was implemented by applying a rigorous protocol of technological interrogation and material metamorphosis:
1. Analysis of memory and material endurance
2. Surgical decomposition and prefabrication
3. Upcycling of timber and infrastructural fractions

Ultimately, the introduction to the Resource Rows case study shows that systemic upcycling does not constitute a subtraction of formal freedom or an invalidating constraint for the designer. Instead, it represents an extraordinary multiplication of tectonic, linguistic, and process opportunities.

Resource Rows thus ceases to be a mere speculative residential module and rises to become a manifest prototype of the "Minable City," where the building is not configured as an end-of-life consumer product, but as a temporary depot of precious resources destined to remain perpetually within the economic and productive cycle.

The genesis (data and methodology)

Developed over a total gross area of 9.148 m²,, the functional program is articulated in a mixed fabric consisting of 92 total housing units (divided into 29 townhouses arranged on three levels and 63 apartments distributed in five-story linear blocks), organized around a central shared courtyard (Lendager, 2019).

From a methodological standpoint, the most complex and innovative challenge faced by the design team involved **redefining the brick lifecycle**. Since the 1960s, the introduction and progressive standardization of high-strength cementitious mortars have made traditional individual brick recovery technically and economically infeasible; the adhesive strength of modern cement binder exceeds the compressive strength of the clay block, causing mechanical breakage during manual or automated cleaning attempts.

Lendager Group codified a methodology of surgical harvesting and envelope prefabrication (**Upcycled Brick Panels**). The facades of several industrial and civic complexes undergoing demolition in the Hovedstaden region (including the historic Carlsberg brewery in Copenhagen and decommissioned primary schools in Roskilde) were mapped, chemically analyzed to exclude contaminants, and subsequently cut in situ using diamond-disc hydraulic saws into standardized square modules measuring 1×1 meter or 1.5x2 meters. These composite macro-panels, consisting of the original bricks and mortar cemented together, were then transported to a prefabrication plant. There, they were embedded and cast within a lightweight concrete back-support matrix, configuring true cantilevered cladding elements which were subsequently dry-mounted on-site onto a metal substructure.

Parallel to the brick supply chain, the technical metabolism of the building intercepted a massive flow of waste from the timber industry and local transport infrastructure. The project recovered approximately 7.5 tons of scrap virgin timber derived from transport crates and formwork for the concrete structural modules used during the construction of the Copenhagen Metro.
To ensure biological durability and weather resistance in outdoor environments as avoiding synthetic chemical impregnants or toxic biocides, the wooden slats underwent a thermal stabilization process based on a reinterpretation of the traditional Japanese technique Yakisugi (Shou Sugi Ban). Controlled superficial carbonization converts the cellulose of the outer layer into inert carbon, sealing the wood against fungi, wood-boring insects, and moisture, while imparting a dark, iridescent coloration to the lightweight facades of the townhouses.

The same urban extraction approach guided the configuration of the interior apartment flooring, built entirely through the recovery of waste strips and second-choice offcuts from the industrial profiling lines of the company Dinesen, which would otherwise have been destined for combustion to produce residual heat.

The systemic closure of material cycles extends to the micro-scale of technological components and the infrastructural structures of the inner courtyard:

- Bioclimatic roof enclosures:
Twenty-nine bioclimatic greenhouses intended for community urban gardens managed by the residents were integrated onto the flat roofs of the complex.

- Aerial connection infrastructure:
To connect the green terraces and roof gardens of the two parallel building blocks, the project reused a prestressed reinforced concrete double-T structural beam (TT-beam), over 12 meters long, extracted intact from the demolition of a nearby industrial warehouse, metrically and functionally specular, built using traditional construction techniques and standard newly extracted materials.

Resource Rows Protocol

The Resource Rows (Ressourcerækkerne) complex in Ørestad Syd, Copenhagen, designed by Lendager Group, acts as a world-first achievement in industrializing and standardizing the reuse of entire masonry sections from historic buildings slated for demolition, alongside secondary timber waste from the metro infrastructure and industrial manufacturing (Lendager, 2019).

01

Mapping, auditing, and logistics of urban demolitions

The protocol begins by identifying complex donor buildings undergoing decommissioning across Denmark. Unlike pre-1960s structures (which used weak lime mortars that easily fractured to recover individual bricks) post-1960s buildings employ high-strength cementitious mortars, making it impossible to separate individual bricks without destroying them.

· Historic Carlsberg Breweries (Copenhagen):
Identification of decommissioned industrial pavilions featuring high aesthetic and historical value red bricks, bonded by irreversible cement mortar.

· Public Schools and Regional Residential Complexes:
Selection of secondary donor sites to diversify brick color tones (yellows and grays), establishing a catalog of recovered materials available for extraction.

· Metro and Dinesen Wood Scraps:
Recovery of decommissioned railway sleepers from the Copenhagen Metro and high-end oak and Douglas fir profiling offcuts from Dinesen manufacturing lines.

02

Non-destructive diagnostics and chemical sampling

Before planning physical extraction, every donor building underwent extensive verification to ensure structural safety and rule out dangerous contaminants accumulated over decades of operation:

· Toxicological Screening and Contaminant Testing (PCBs, PAHs, and Lead):
Core drilling and chemical analyses were performed on industrial donor facades to detect polychlorinated biphenyls (PCBs) in joint sealants, polycyclic aromatic hydrocarbons (PAHs) from atmospheric pollution, or lead-based paints. Only chemically inert masonry portions were approved for recovery.

· In-Situ Compression Tests and Freeze-Thaw Testing:
Implementation of flat jacks and load tests to determine the residual mechanical strength of the existing masonry. Samples were extracted to test historical brick freeze-thaw durability in climate chambers, guaranteeing long-term weather resistance in the Scandinavian climate.

03

Wet cutting and industrial prefabrication

To overcome the challenge of indissoluble cement mortar, Lendager devised and patented a modular cutting and assembly technique:

· Wet Cutting with Diamond Saws:
Donor building masonry was not demolished; instead, it was cut in situ into standardized square modules measuring 1x1 m (or submultiples) using industrial water-cooled diamond-disc saws. This process preserved brick integrity and the original existing mortar bonding them.

· Framing and Factory Prefabrication:
The 1m^2 modules (each containing approximately 60 bricks with their historic mortar) were transported to a manufacturing plant. There, they were cleaned of loose debris, stabilized, and cast within a lightweight concrete back-frame or steel brackets, creating prefabricated cladding panels ready for the construction site.

· Mosaic Color Composition:
Modules sourced from different donor buildings (red, yellow, dark) were arranged within the prefabricated panels according to a geometric layout designed to celebrate the historical heterogeneity of the materials, turning chromatic variation into an architectural asset.

04

Chemical-physical tests and regulatory requirements

The new prefabricated panels composed of recovered brick modules experienced rigorous laboratory testing to satisfy strict building certifications imposed by BR18 regulations:

· Wind Load Resistance and Tensile Testing:
Prefabricated wall panels were mounted on test benches and subjected to pressure and suction loads to simulate high-altitude wind forces in Ørestad. The holding capacity of metal anchorage brackets integrated into the joints between brick modules was verified.

· Thermal Transmittance Verification of the Façade Assembly:
The recovered brick module cladding was validated as the outer layer of a high-performance ventilated façade. The air cavity and thick internal mineral wool insulation layer ensured an overall thermal transmittance value compliant with Nearly Zero-Energy Building (NZEB) standards.

05 Parametric Optimization

Due to inevitable dimensional variations and geometric defects inherent in modules cut from different buildings, the design relied on parametric tools to orchestrate production:

· Digital Mapping of On-Site Tolerances:
Every 1 m^2 module was scanned to record exact thickness and edge imperfections. Using a geometric optimization algorithm in a BIM environment, modules were distributed across the façade to reconcile dimensional tolerances, minimizing adjustment joint widths during assembly.

· Integration of Reclaimed Wood at Thermal Bridges:
Metro sleepers and Dinesen offcuts (processed and longitudinally jointed) were integrated into façade details around window reveals and accessible roof parapets, optimizing construction details against thermal bridging.

06 Design for Disassembly

The entire construction system of Resource Rows was engineered to guarantee total component reversibility, eliminating wet cementitious binders or expanding foam sealants during on-site installation:

· Expansion Joints and Suspended Mounting:
Prefabricated 1x1 m brick modules were suspended from the building's reinforced concrete structural frame via a dry stainless steel bracket-and-rail system. Horizontal and vertical joints between modules were sealed with weather-resistant dry EPDM rubber gaskets, allowing every single panel to expand freely and be individually removed for maintenance.

· Reversible Wooden Parapets and Green Roofs:
Rof-hut claddings and communal green roof planters were constructed by dry-assembling railway sleepers and Dinesen offcuts using stainless steel screws and bolted brackets, avoiding chemical glues and toxic paints to preserve wood purity.

· Closing the Lifecycle Loop of Modules:
At the end of the building's lifecycle, the absence of installation mortars on-site allows brick modules and wood components to be quickly and cleanly unscrewed and unclipped. The 1 m^2 panels can be removed intact and transported to a new construction site, ready for re-introduction into a third building cycle without undergoing crushing or thermal recycling.

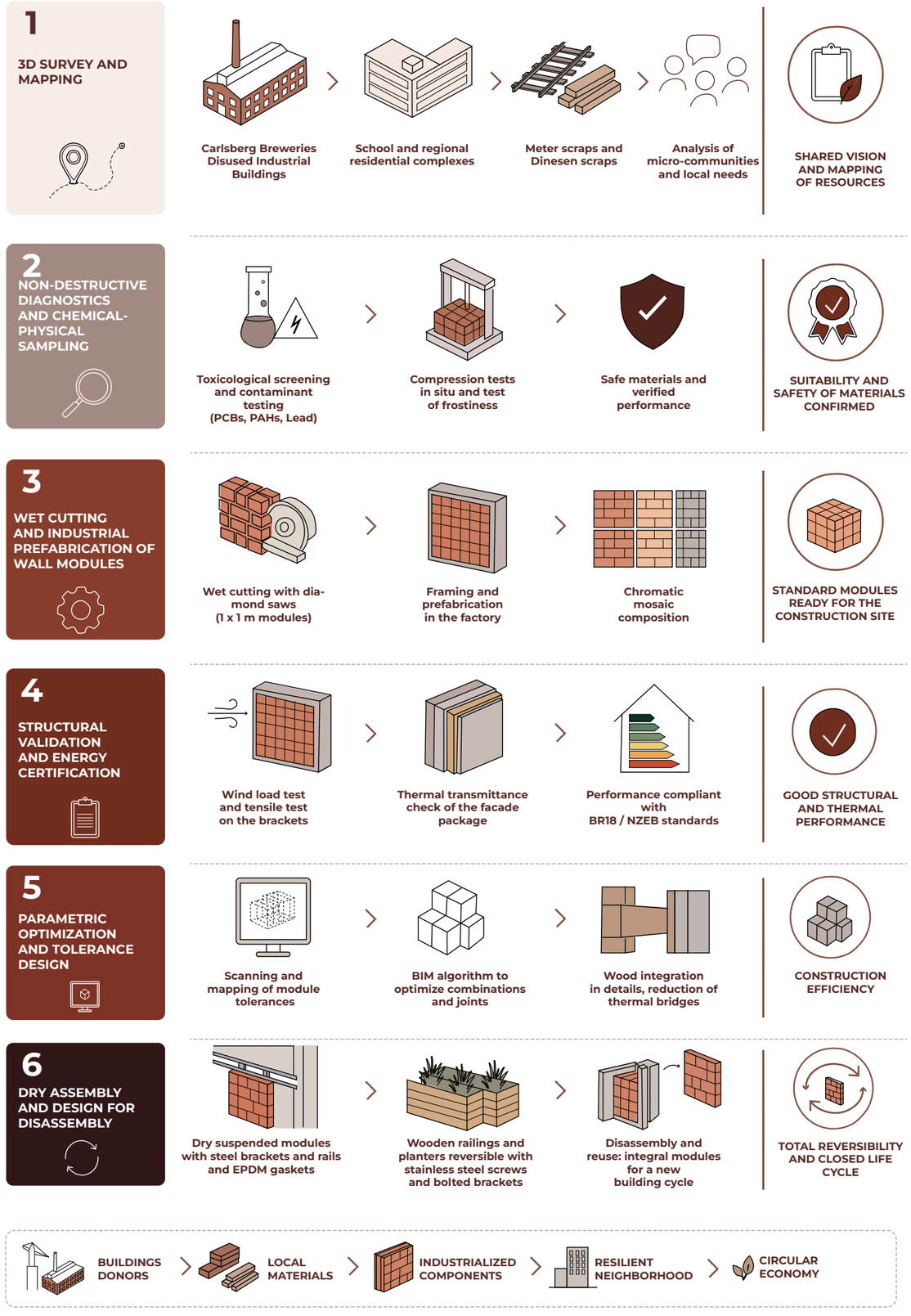


Fig. 41_Resource Rows Protocol. Source: *personal processing*

Quantitative analysis

The systematic application of upcycling protocols at Resource Rows enabled the diversion of a total of **463 tons of secondary and demolition building materials** from urban and industrial waste streams, establishing a high Landfill Diversion Rate (LDR) (Lendager Group & MOE, 2019):

The facade architecture contains 84 prefabricated macro-modules of historic masonry. By avoiding the mechanical separation of individual bricks (which would have broken over 70% of the pieces due to modern cementitious mortars) mass balance calculations recorded a recovery efficiency close to 100% for the masonry sectioned from the Carlsberg and Roskilde school sites.
Reusing pre-assembled historic brick blocks saved 500 grams of CO_2 per individual piece, representing a 70% reduction in embodied emissions compared with producing and firing a standard virgin clay brick.

The 29 rooftop bioclimatic greenhouses, engineered by recycling window frames and single panes from urban regeneration projects, achieved an 86% reduction in equivalent CO_2 compared to extruding and assembling new aluminum or PVC window units.

Integrating 7.5 tons of scrap timber from Copenhagen Metro formwork for exterior cladding generated a 60% reduction in the embodied carbon footprint of the facade subsystem.

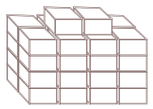
Thermal integration between high-efficiency photovoltaic solar panels and centralized water-source heat pump systems guaranteed full satisfaction of the building's thermal demands.
Despite the mixed nature of the reclaimed masonry blocks, the ventilated wall stratigraphy ensures thermal transmittance coefficients aligned with tough Scandinavian energy regulations. It completely prevents linear thermal bridges thanks to the millimeter-precision diamond wire cutting performed during the industrial stabilization phase of the modules.

Life Cycle Costing (LCC) analysis showed absolute cost neutrality between the circular building and traditional speculative complexes built in the Ørestad Syd area.

The elevated operational costs tied to geometric-structural due diligence, material salvage, and reverse logistics had been mathematically offset by the complete elimination of raw material purchasing costs and the avoidance of landfill disposal ecotaxes.

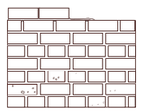
Quantitative estimate

Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



1 100 m² MASONRY

BEFORE: Solid bricks pre-1960
AFTER: Facades and load-bearing walls



250 m² MASONRY

BEFORE: Post-1960 solid bricks
AFTER: Internal walls and partitions



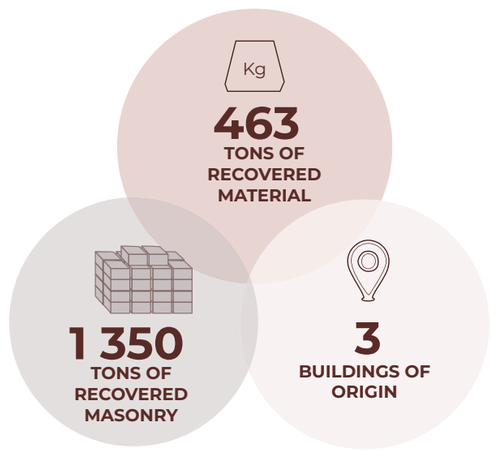
480 BRICK LINTERS

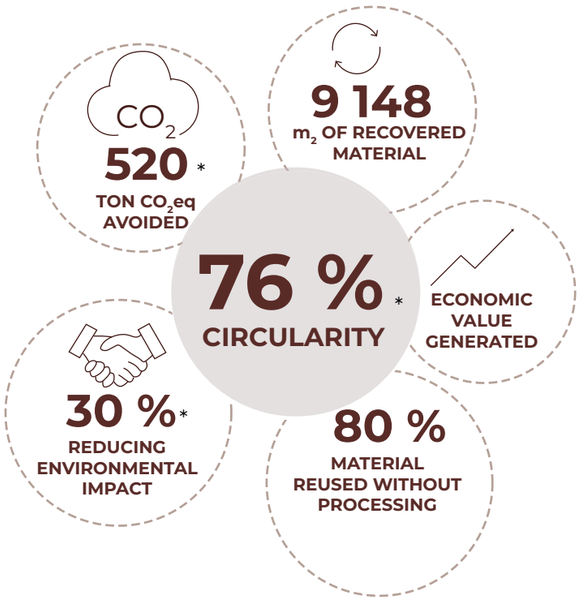
BEFORE: Brick lintels
AFTER: Openings and load distribution



6 TONS MORTAR

BEFORE: Historic mortar
AFTER: Reuse in joints and bedding





* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 42_Quantitative analysis of Resource Rows. Source: *personal processing*

Economic analysis

The project demonstrates absolute cost neutrality compared to a twin residential building constructed according to linear building canons, converting environmental liabilities into levers of profitability and financial risk mitigation (Lendager Group & MOE, 2019).

The savings generated by the economic model of Resource Rows do not reside solely in the avoidance of purchasing industrial components, but are founded on the elimination of disposal costs and the macroeconomic protection of the short supply chain.

• Brick Raw Material:
In a macroeconomic context defined by high energy price volatility, sourcing from local urban mines neutralized the risk of fluctuations in the cost of cladding materials.

• Reverse Logistics and Urban Proximity:
By avoiding the movement of heavy vehicles to extra-urban storage hubs or crushing plants, the project showed a net reduction in fuel expenses and associated logistics burdens tied to road transport.

• Landfill Tax:
Danish legislation imposes severe taxation on unsorted demolition waste. Diverting a total of 463 tons of building and industrial waste from downcycling or landfill destinations generated a direct and immediate saving on tipping fees.

Additional Costs (Extra-costs)
• Industrialization of the Cutting Process:
The combination of ventilated facades consisting of preassembled second-hand brick modules required significant initial investments for process engineering.

• Qualified Labor:
Transforming 7.5 tons of metro waste wood into exterior cladding required specialized labor to apply the controlled carbonization technique Shou Sugi Ban. While this artisanal-industrial thermal treatment eliminated future costs for chemical impregnating agents, it generated a 25% extra cost in the cladding preparation phase compared to newly produced raw timber slats.

• Performance Certification:
Obtaining special technical approvals increased certification expenses, configuring itself as a necessary investment to ensure the bankability of the work.

The Value of the "Future-Proof" Asset
NREP's decision to finance an intervention based on systemic upcycling finds its ultimate justification in the long-term appreciation of the real estate asset's capital value (Asset Value).

• Market Premium and Attractiveness:
The strong architectural identity of Resource Rows, tied to the material narrative and historical memory of the city's old breweries, generated a high immaterial value perceived by the market. This translated into a commercial absorption speed superior to the district average of Ørestad Syd, registering sell-outs for both townhouses and linear apartments in record times, therewith reducing vacancy risk.

• Resilience to Decarbonization Policies:
Having anticipated the restrictions introduced by subsequent Danish regulatory amendments, the property is natively positioned out of harm's way from climate obsolescence risks. Resource Rows avoids the specter of capital depreciation that will affect buildings with high embodied carbon content, presenting itself as a resilient asset for the coming decades.

• Preferential Access to Institutional Capital:
The circularity metrics and the net target of a 29% reduction in overall carbon footprint allowed the client to integrate the project within ESG protocols. Such compliance unlocked access to institutional investment funds specialized in sustainable finance.

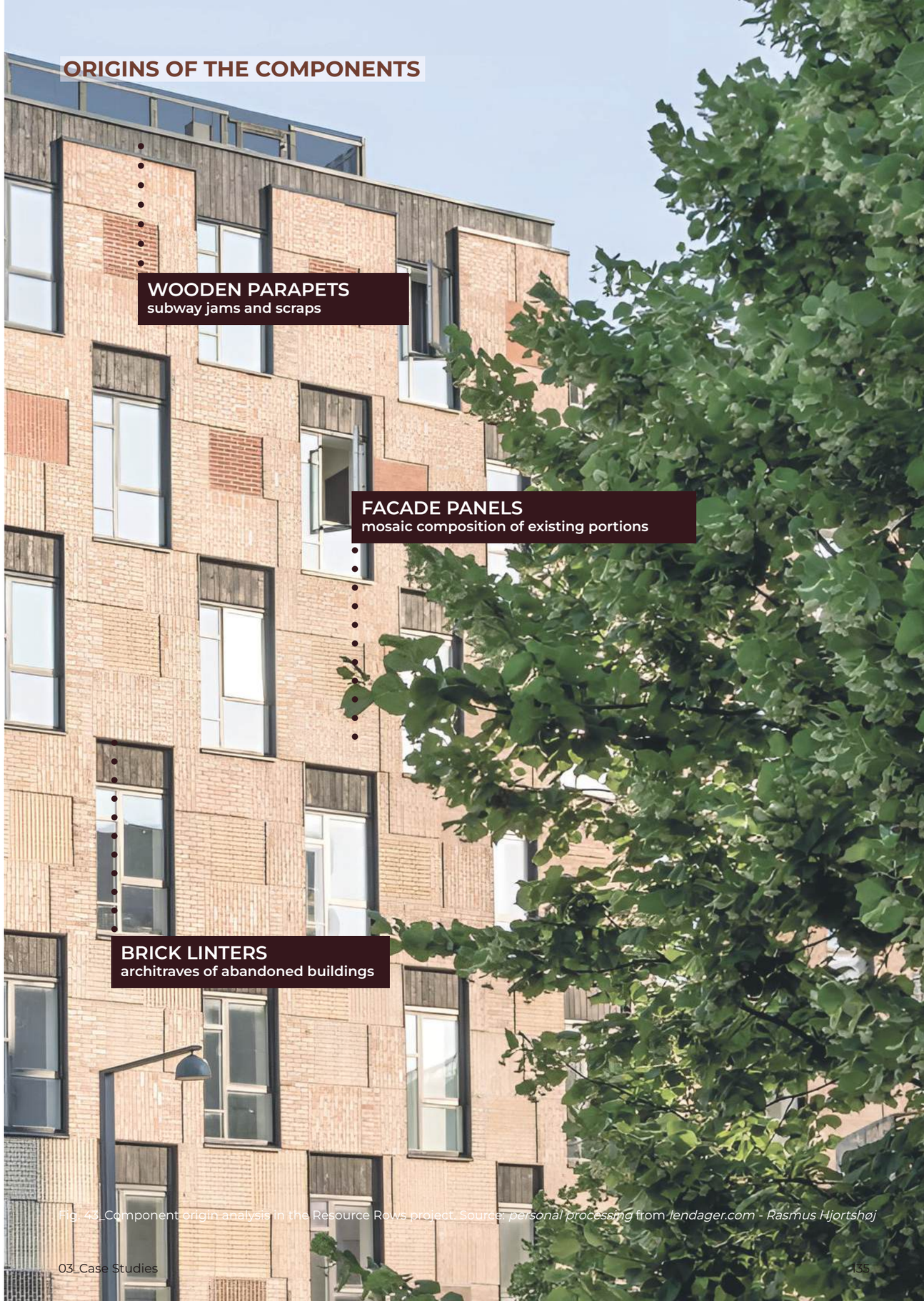


Fig. 43_Component origin analysis in the Resource Rows project. Source: *personal processing* from *lendager.com - Rasmus Hjortshøj*

Problems and Successes: Lesson Learned

The success of the intervention lies precisely in Lendager Group's ability to decode logistical and performance-related criticalities, transforming them into vectors of technological innovation and commercial value for the mass residential market (Lendager, 2019).

The Key Problem: Regulatory Gaps and the Certification of Second-Hand Brickwork

The complete absence of a standardized CE marking for the brick macro-modules salvaged from the decommissioned Carlsberg breweries initially halted the permitting process, as the competent authorities equated the historical brick with a material lacking original performance certification.

• Destructive Testing Campaign:
In collaboration with specialized research institutes, the macro-modules underwent compressive stress tests, climatic chamber evaluations, and driven-rain simulations to analytically map the bearing capacity and water-tightness of the historical joints.

• Experimental Certification:
The empirical data collected allowed for the drafting of customized technical datasheets for each extraction lot, providing control authorities with the same structural and physical guarantees required for newly manufactured virgin industrial building components.

• Engineering of the Façade Joint:
To compensate for the millimetric tolerances resulting from diamond wire cutting performed on the demolition site, a dry-mounting system on a flexible metal substructure was designed, capable of absorbing micro-movements of the second-hand masonry without triggering cracking or thermal bridging.

Commercial Success

The most significant success of Resource Rows lies in proving that the adoption of reclaimed materials does not depreciate the property; rather, it improves its utility value and attractiveness within the speculative real estate market. The market rewarded the chromatic uniqueness and shifting texture of the preassembled facades, preferring them over the standardized building solutions of competitors. The high ESG rating associated with the project attracted a demographic willing to economically value the ethical and ecological investment, demonstrating that the material narrative of the urban mine constitutes an exceptionally powerful real estate marketing lever.

Towards Reversible Architecture

The impossibility of modifying the brick macro-modules once positioned on-site necessitated highly coordinated design within a BIM environment. The exterior wooden cladding panels and pre-fabricated facade elements were installed via exposed, reversible mechanical connections, enabling the inspection, maintenance, or replacement of individual components without damaging the insulation layer or the internal load-bearing structure.

Resource Rows ceases to be understood as a static and definitive artifact, configuring itself instead as a material bank temporarily lent to the urban scale. Fifty or sixty years from now, at the end of the complex's useful lifecycle, the building can be surgically deconstructed: the brick modules and timber framing, already engineered for dry disassembly, will not feed landfills yet will be re-introduced directly into new architectural value chains.

The economic and commercial success of Resource Rows definitively validates this paradigm shift: sustainability and systemic upcycling do not represent formal limitations or sunk costs, but rather act as powerful multipliers of economic, cultural, and environmental value for the cities of the future.





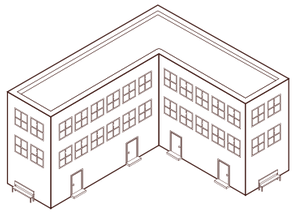




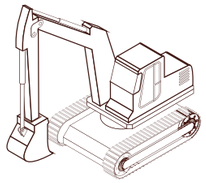


Fig. 44_Photographs of the Resource Rows project construction site. Source: *lendager.comn.com - Rasmus Hjortshøj*

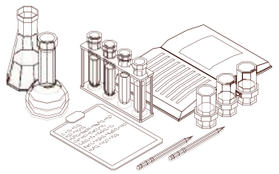
SYNTHESIS



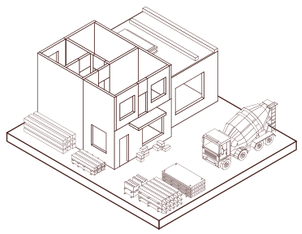
EXISTING BUILDINGS



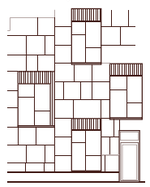
URBAN MINING



CHEMICAL SCREENING



DESIGN FOR DISASSEMBLY



RESOURCE ROWS

-520 t *
CO_2 eq. avoided

-33 % *
total cost

-80 % *
waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 45_Summary diagram of the Resource Rows project. Source: *personal processing*

Fig. 46_Resource Rows. Fonte: *lendager.com - Rasmus Hjortshøj*

Upcycle Studios

Designer:
Lendager Group

Clients:
NREP | AG Group

Site:
Copenhagen, Denmark (3 909 m^2)

Year:
2015 - 2018

Size M
Single building

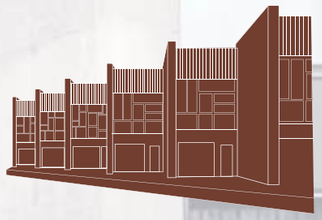


Fig. 47_Upcycle Studios - Lendager Group, Copenhagen, 2018. Source: *lendager.com - Rasmus Hjortshøj, Optic Circus*

The Upcycle Studios by Lendager Group stand as the operational manifesto of territorial “Material Sourcing.” In this project, upcycling evolves from an experimental practice into a serial industrial process, demonstrating that it is possible to construct high-performance contemporary residential complexes by drawing exclusively on local industrial waste and demolition residues (Lendager, 2018).

Lendager Group breaks the linear logic of the traditional construction site, transforming it into a sophisticated assembly hub for second-generation products.

The introduction of this case study is fundamental to providing the design studio with the means to understand how upcycling is truly practiced today: not through the romantic recovery of the single piece, but through the creation of a short-chain reuse system capable of reducing the carbon footprint by 45%.

The project introduces three methodological advances that every architect should integrate into their workflow:

1. Design Inversion:
In the Upcycle Studios, aesthetics are not an a priori imposition by the designer. The form and materiality of the buildings are the direct result of waste availability within a few kilometers of the construction site. This shifts the architect’s role toward that of a resource explorer.

2. Performance Certification:
The project addresses the most complex regulatory challenge: how to guarantee that a 50-year-old brick or reclaimed glass complies with current energy standards (Danish BR18)? Lendager developed testing protocols that transform the used component into a new product in the eyes of the law and insurance companies.

3. Panel Engineering:
Rather than cleaning individual bricks, Lendager devised the cutting of entire masonry modules from buildings undergoing demolition. This insight transforms upcycling from manual labor into an automated and scalable process.

The Upcycle Studios are therefore not simply a sustainability experiment, but a mature business model. They demonstrate that waste is not a limitation to creativity, but a high-value-added raw material that, when properly managed, makes it possible to drastically reduce CO_2 emissions without sacrificing living comfort or real estate value.

The genesis (data and methodology)

Lendager Group starts from a brutal realization: in a standard modern residential building, approximately 40% of total CO_2 emissions (calculated over the entire lifecycle) are generated even before the tenant receives the keys. This embodied carbon is trapped in finishing materials, facades, and interior partitions (Lendager, 2018).

The “Resource Rows” Methodology

Lendager has implemented an industrial methodology called “Resource Rows.” This approach converts the architectural design studio into a material intelligence agency.

· Local Waste Audit:
Before drawing the first line of the project, the team mapped waste streams from large Danish industries and public infrastructure demolition plans within a limited radius.

· Standardization of Waste:
The methodological challenge was to transform heterogeneous waste into a standardized building component. Lendager did not seek loose bricks, but instead identified obsolete buildings from which pre-assembled wall portions could be extracted. This makes it possible to maintain the installation speed of an industrial construction site while using second-hand materials.

Environmental Data

The numbers behind the Upcycle Studios are the primary argument in favor of the model’s scalability. This is not a marginal reduction, but a shift in the scale of environmental impact.

· 45% CO_2 Reduction:
Life Cycle Assessment (LCA) studies conducted on the complex showed that the total carbon footprint was reduced by 45% compared to a baseline construction built with virgin materials.

· Indirect Energy Savings:
The greatest savings derive from avoided production. Producing a new brick requires furnaces at 1000°C; producing glass requires even higher temperatures. Recovering these materials means freezing the energy expended decades ago and reusing it, preventing new emissions into the atmosphere.

· Zero Waste Goal:
The project proved that it is possible to divert tons of noble materials (wood, glass, brick) from landfills, materials that on a normal construction site would be treated as disposal costs.

Design-by-Availability

Here, the architect accepts a role as mediator between necessity and resource.

· Resulting Aesthetics:
The aesthetics of the Upcycle Studios are not a formal whim, but the visual manifestation of availability. If the demolition market offers red brick modules from an old school and oak wood scraps from a flooring manufacturer, the building will assume that exact chromatic and material identity.

· Design Flexibility:
This approach requires superior technical competence: construction details cannot be standard textbook solutions, but must be designed to accommodate components with variable tolerances. The joint between a reclaimed brick panel and an industrial scrap window becomes the primary architectural element.

· The Building as a Material Bank:
Ultimately, the Lendager philosophy views the building not as a finished product, but as a temporary depot of resources. Every component is mechanically assembled so that it can one day be extracted and reused again, definitively closing the loop of matter.

Upcycle Studios Protocol

The Upcycle Studios project, developed by Lendager Group in the experimental district of Ørestad in Copenhagen, represents one of the most advanced applications worldwide of multi-component industrialisation applied to building and industrial waste (Lendager, 2018).

01

Supply chain tracking and reverse logistics

The protocol begins with the mapping and systematic interception of waste streams across three separate scales (building, infrastructural, and industrial) before they are directed toward thermal downcycling processes or landfill disposal:

· The windows of the Aalborg East residential complex:
Double-glazed windows with wooden frames removed during a massive energy retrofitting plan. The components showed excellent mechanical integrity of the frames but obsolete thermal performance.

· Solid wood offcuts from the Dinesen facility:
End sections of high-end oak and Douglas fir planks, historically destined for industrial incineration to generate thermal energy in production plants.

· Excavation debris from the Cityringen metro construction site:
Limestone rocks and waste concrete blocks produced during the boring of the Copenhagen metro's underground tunnels.

02

Selective diagnostics and characterization

The suitability of the materials was verified through physical and chemical testing to rule out contaminants and check chemical stability prior to any industrial processing:

· Chemical screening and lead testing on window frames:
Spectrometric tests were conducted on the old Aalborg East windows to detect the presence of lead-based paints or PCB-containing sealants.

· Moisture analysis and wood classification:
Dinesen offcuts underwent hygrometric checks to ensure a constant moisture content (stabilised at 8-10%), which is fundamental to preventing cracking or geometric deformations after mechanical processing.

03

Processamento meccanico e standardizzazione

The raw reclaimed materials were standardised and engineered to bridge the dimensional and geometric gap typical of waste material, converting them into industrial semi-finished products ready for installation:

· Engineering of the coupled window:
The old, cleaned windows, devoid of metal hardware, were coupled face-to-face in pairs and integrated within a new, unified perimeter subframe made of high-density glulam timber.

· Industrial jointing of timber slats:
The short solid wood Dinesen offcuts were trimmed at the ends and longitudinally jointed via male-female micro-finger profiling and high-structural-strength, formaldehyde-free polyurethane resins, recreating continuous boards of standard length.

04

Validation of thermal and physical performance

To obtain building type-approval in accordance with the strict requirements of Danish BR18 regulations, the engineered components underwent laboratory testing to certify their performance:

· Thermal transmittance testing in a hot box:
The four-layer coupled window module was tested to measure the overall thermal transmittance coefficient. The tests recorded a final value of less than 0.8 W/m^2K, equivalent to that of a newly produced triple-glazed argon unit, with a 95% saving in CO_2 emissions associated with glass melting.

· Accelerated ageing testing on jointed wood:
Samples of the slats obtained through finger-jointing were subjected to thermal shock and humidity cycles to validate the integrity of the glued joint both indoors and outdoors (on facades and terraces).

· Axial compression tests on recycled concrete:
Specimens of the new cementitious mix formulated with 100% recycled aggregate were subjected to destructive crushing at 28 days. The use of next-generation superplasticiser admixtures compensated for the water absorption of the porous aggregate, assuring a structural strength class fully compliant with Eurocodes for load-bearing walls.

05 Parametric Optimization

The dimensional and aesthetic variability of the materials was managed using parametric digital models to optimise layout and increase resource efficiency:

· Planning of the macro-air cavity:
Through dynamic thermophysical simulations in the BIM model, the internal distance between the two coupled windows was optimised to 50 mm. This static macro-air gap acts both as a thermal insulator and as a highly efficient acoustic barrier against the urban noise of Ørestad.

· Composition algorithms for the wood mosaic effect:
The arrangement of the oak and Douglas fir slats on walls and floors was optimised with an algorithmic method to minimise cutting waste on site. The result is a staggered, textured surface that celebrates the intrinsic chromatic diversity of the reclaimed wood.

· Exploitation of active thermal mass:
The load-bearing walls made of recycled concrete were positioned in the central core of the buildings in correspondence with large glazed openings, allowing the walls to store daytime solar heat and gradually release it during the night.

06 Design for Disassembly

Site techniques and joint design details were configured to facilitate future maintenance and prevent material contamination, making sure that each component can be disassembled and recycled at the end of its lifecycle:

· Clamp installation of window frames:
The fenestrated modules were not walled in or sealed with permanent polyurethane foams, but dry-installed using EPDM rubber sealing gaskets and flanged mechanical brackets. This allows easy replacement of individual panes or clean removal of the entire frame without damaging the masonry structure.

· Ventilated wooden substructures and mechanical installation:
The Dinesen wooden facade slats were mounted on a ventilated wooden lath substructure using exposed stainless steel screws. This system excludes the use of chemical glues, facilitating the selective replacement of weather-degraded slats and enabling the total recovery of the wood at end-of-life.

· Exposed finishes and absence of plasters:
The exposed concrete of the internal load-bearing walls was not coated with plasters, plasterboard, or synthetic paints. The walls were left bare, showing the marks of the wooden formwork and the gradations of the metro aggregates. This choice eliminates the use of polymeric filler chemicals, preserving the purity of the cementitious matrix for future crushing and third-generation recycling.

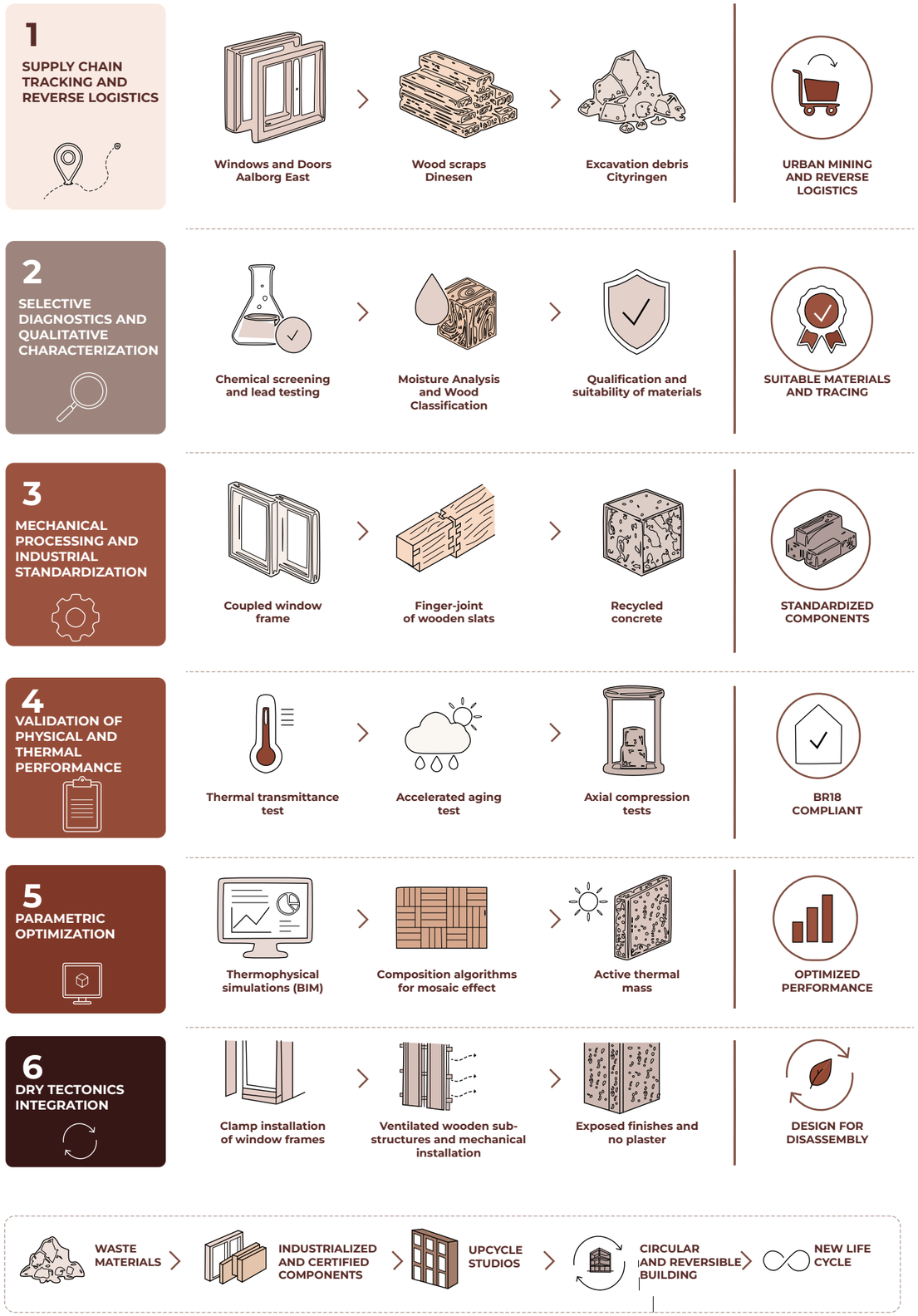


Fig. 48_Upcycle Studios Protocol. Source: *personal processing*

Quantitative analysis

The data collected by the Lendager Group transforms the building into a scientific case study, where success is measured through three primary parameters: avoided carbon, recovered mass, and certified thermal efficiency (Lendager, 2018).

CO_2 Savings

The most relevant data for the European green taxonomy concerns the reduction of emissions associated with the production and transport of materials.

· The Data:
The selective recovery of glass and bricks alone enabled a net saving of approximately 50 kg CO_2e/m^2. Upon extension to the entire building organism, the total carbon footprint was 45% lower than that of a "twin" construction built with virgin materials.

· Analysis of Avoided Processes:
This saving stems from having bypassed the most energy-intensive industrial phases. Producing a new brick requires firing at around 1000°C, while glass melting occurs at approximately 1500°C. By using existing masonry modules and double-glazing units, the energy expended for their original creation (decades prior) is frozen and reused, eliminating the need for new combustion processes and the extraction of raw materials (sand and clay).

Percentage of Recovered Material

Lendager's challenge was not limited to recovering small aesthetic details, but aimed to impact the critical mass of the building to divert significant streams away from landfills.

· Over 25% by Weight:
More than a quarter of the building's total weight consists of certified reclaimed materials. This is an exceptional figure considering that heavy load-bearing structures (cast-in-place reinforced concrete foundations and floor slabs) are usually excluded from reuse on account of regulatory or urgent structural safety reasons.

· Composition of Mass:
This percentage was achieved through the massive use of cut brick panels (approximately 450 tons of recovered brick) and solid wood flooring. Environmentally, this means transforming hundreds of tons of potential inert waste into a high-economic-value real estate asset with guaranteed durability.

Energy Performance

One of the most persistent myths about upcycling is that using used components inevitably leads to less insulated or technically obsolete buildings. The Upcycle Studios categorically disprove this prejudice through regulatory compliance.

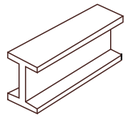
· BR18 Standard:
The building strictly complies with Danish BR18 regulations, one of the strictest in the world for thermal transmittance and airtightness.

· Hybrid Component Engineering:
The secret to success lies in pairing recovered raw materials (such as 1990s double-glazing) with modern assembly technologies (new high-tightness wooden frames).

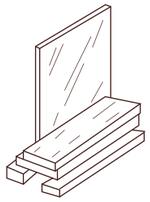
· Operational Result:
The building not only consumes very little energy for heating (operational efficiency), but also has already saved nearly half of its emissions during the construction phase (embodied efficiency). This creates a dual environmental dividend unique in the contemporary architectural scene.

Quantitative estimate

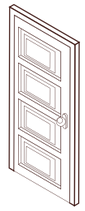
Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



320 BEAMS STEEL
BEFORE: Former industrial structures
AFTER: Primary Structure



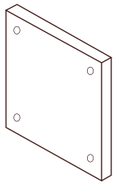
84 COMPONENTS GLASS & WOOD
BEFORE: Former windows and facades
AFTER: Interior and exterior fixtures



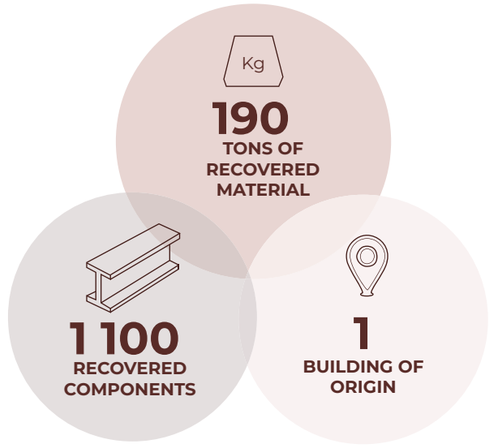
210 DOORS WOOD
BEFORE: Former interior doors
AFTER: Doors and paneling

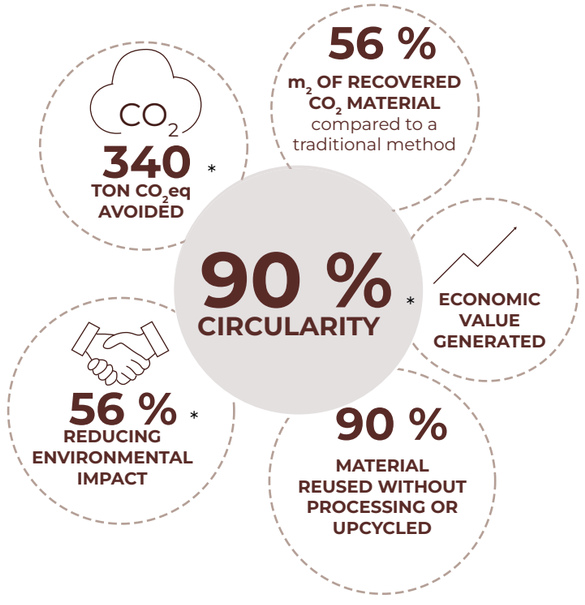


1 250 m^2 BRICKS
BEFORE: Existing masonry
AFTER: Interior cladding and walls



190 PANELS CONCRETE
BEFORE: Former attics and flooring
AFTER: Furnishings and surfaces





* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 49_Quantitative analysis by Upcycle Studios. Source: *personal processing*

Economic analysis

For a design firm, the economic analysis of the Upcycle Studios is fundamental to dismantling the prejudice that sustainability necessarily means unprofitability. The project demonstrates that the circular economy is not a material-saving strategy, but rather a strategy for creating added value (Lendager, 2018).

Raw Material Costs

In a traditional construction site, the purchase of virgin materials represents one of the heaviest and most volatile budget items, subject to political changes and energy crises.

· 60% Reduction:
For components subject to upcycling (bricks, glass, wood), material acquisition costs were drastically reduced, often limited solely to logistics expenses and extraction rights fees at demolition sites.

· Financial Stability:
By utilizing local urban mines, the studio shields itself from the volatility of global markets. Raw materials cease to be an uncertain variable and become a readily available territorial asset, stabilizing the operation's business plan.

Process Extra-Costs

The savings achieved on materials are partially reinvested in the transformation and technical validation phases. This is where the design studio's work concentrates.

· The Impact of Labor (+5%):
Total construction costs were approximately 5% higher than the market average. This surplus is generated by three critical factors:
1. Cutting Technology: Using diamond saws to section walls requires specialized operators and longer execution times than indiscriminate demolition.
2. R&D and Re-framing: Designing new frames for reclaimed double-glazing units required prototyping and laboratory testing to ensure thermal performance.
3. Certification: The cost of validating the safety and durability of used materials in the eyes of insurance companies and banks.

This 5% extra cost should not be seen as a burden, but rather as a reallocation of the budget toward project quality and technical innovation

Sales Premium Price

The most surprising data from Lendager's operation is the market's reaction: upcycling was perceived as an attribute of contemporary luxury rather than an economic compromise.

· 10-15% Price Premium:
The housing units were sold or rented at a significant premium compared to standard buildings in the Ørestad district.

· The Aesthetics of Uniqueness:
Thanks to Design-by-Availability, every apartment is a unique piece. The brick pattern varies from module to module, and the Dinesen parquet features unrepeatable grain patterns. This non-industrially reproducible exclusivity attracts an elite clientele.

· ESG Value and Ecological Consciousness:
Modern buyers attribute real monetary value to certified carbon reduction. The building sells not just square meters, but a positive environmental impact, transforming ethics into a concrete competitive advantage that accelerates sales velocity (absorption rate).

ORIGIN OF THE COMPONENTS



Fig. 50_Analysis of the origin of components in the Upcycle Studios project. Source: *personal processing* from *lendager.com* - - *Rasmus Hjortshøj, Optic Circus*

Problems and Successes: Lesson Learned

The Upcycle Studios project represented a true “stress test” for the entire Danish construction supply chain. While the theory of the circular economy is fascinating, its practical application clashed with insurance barriers and technical prejudices that required unprecedented solutions, converting every critical issue into a competitive strength (Lendager, 2018).

The Problem: The “Regulatory Void” and Performance Guarantees

The most difficult challenge encountered by Lendager was not formal in nature, but legal and insurance-related. The modern building market relies on established product standards: a brick or window supplier issues a Declaration of Performance (DoP) guaranteeing frost resistance or thermal transmittance for decades.

· The Unknown Factor of Time:

How to guarantee that a brick extracted from a 1960s school, after 50 years of exposure, will not be subject to spalling due to frost action? How to ensure that a reclaimed double-glazing unit does not present micro-leaks of Argon gas that would neutralize its insulating power within months?

· Insurance Company Rejection:

Initially, insurance companies showed strong resistance to covering buildings constructed with waste, fearing structural failures or premature degradation of envelope materials that would compromise the validity of the ten-year post-construction warranty.

The Solution: Validation Protocols and Forensic Engineering

Lendager Group understood that scaling upcycling required transforming into a certifying body. The studio ceased to be merely a designer and became the technical guarantor of the material.

· Accelerated Aging Tests:

To convince investors and financial partners, Lendager subjected samples of bricks and windows to extensive thermal cycles and advanced laboratory tests. Forensic analysis was conducted on the porosity of the masonry and the integrity of the seals.

· Negotiation with Stakeholders:

The studio developed a proprietary internal certification protocol. This dataset made it possible to demonstrate that reclaimed materials, having already survived fifty years of real exposure to atmospheric agents without degrading, were intrinsically more reliable than many new products never tested in the field. This approach permitted for the negotiation of standard insurance premiums, breaking down the barrier of legal uncertainty.

The Success: The Aesthetics of “Sincere Luxury”

The most disruptive innovation was semantic and perceptual: Lendager transformed technical flaws into a distinctive brand signature.

· From Perfection to Authenticity:

Traditionally, mass residential construction aims for aseptic standardization. The Upcycle Studios instead celebrated the chromatic variations of the bricks and the irregular grain of Dinesen wood. This imperfect aesthetic was received by the market as a form of artisanal and conscious luxury, akin to Japanese Wabi-sabi aesthetics applied to Northern European architecture.

· Elimination of Secondary Finishes:

An economic success derived from this choice was the elimination of costs for plasters, covering paints, or expensive surface treatments. Leaving the material exposed allowed for:

1. Reducing construction site costs by eliminating subsequent processing steps.
2. Improving indoor air quality (IAQ) by eliminating chemical substances (VOCs) present in paints.
3. Facilitating future disassembly, as the materials are not contaminated by glues or coatings that would prevent a third lifecycle.



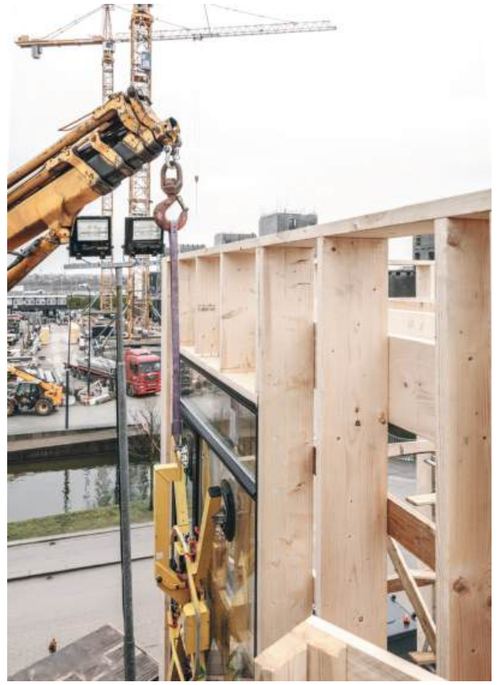
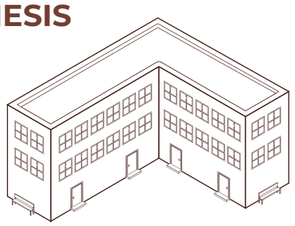


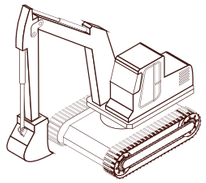


Fig. 51_Photographs of the Upcycle Studios construction site. Source: lendager.com- Rasmus Hjortshøj, Optic Circus

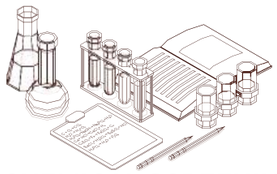
SYNTHESIS



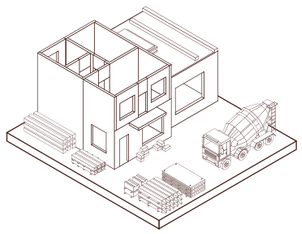
EXISTING BUILDINGS



URBAN MINING



CHEMICAL SCREENING



DESIGN FOR DISASSEMBLY



UPCYCLE STUDIOS

-340 t *
CO_2 eq. avoided

-32 % *
total cost

-90 % *
waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 52_Upcycle Studios project summary diagram. Source: *personal processing*

Fig. 53_Upcycle Studios. Source: *lendager.com - Rasmus Hjortshøj, Optic Circus*

BlueCity Offices

Designer:
Superuse Studios

Client:
BlueCity

Site:
Rotterdam, Netherlands(1 300 m^2)

Year:
2017

Size M
Single building

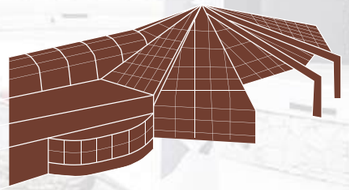


Fig. 61_BlueCity Offices - Superuse Studio, Rotterdam, 2017. Source: *superuse-studios.com*

The BlueCity project in Rotterdam, curated by Superuse Studios, acts as one of the most emblematic and radical case studies in contemporary architectural upcycling, elevating the concept of reuse from a simple recovery strategy to a true model of industrial symbiosis. While previous analyses focused predominantly on the conservation of load-bearing structures or the recycling of material components, the intervention in the former Tropicana water park shifts the axis of discussion toward integrated flow management (Superuse Studios, 2017).

The building, an imposing 1980s structure that long remained unused as a post-industrial urban wreck, is reinterpreted as an open-air urban mine capable of generating value not only through land savings, but through a radical redefinition of the architect's professional practice.

The methodological fulcrum that makes BlueCity unique in the European landscape is the systematic inversion of the traditional design process operated through the tool of the Harvest Map. In a conventional approach, the architect defines the shape and technical performance of components and then orders them from the virgin materials market; conversely, Superuse Studios subordinates design to the actual availability of resources found within a local radius.

This material-driven approach requires a radical reconfiguration of the architectural studio, which must integrate skills in logistics, flow intermediation, and real-time material diagnostics. The tectonics of the BlueCity offices, characterized by the creative reuse of thousands of square meters of discarded window frames and metal profiles from neighboring demolitions, does not respond to an aesthetic whim, but is the direct result of technical negotiation between building regulations and the material reality of the waste.

Investigating the case of BlueCity therefore means analyzing how it is possible to achieve a circularity threshold close to 90% without sacrificing spatial quality or economic feasibility. The challenge faced by the designers lies in overcoming bureaucratic barriers related to the performance certification of reclaimed components, converting each architectural element into a database of saved embodied energy.

Through this intervention, the studio demonstrates that upcycling can act as an engine of urban regeneration capable of cutting CO_2 emissions by 68% compared to a standard renovation, while supplying a concrete response to the resource crisis.

The analysis that follows will explore in detail the harvesting protocols, regulatory adaptation approaches, and economic balances that make this circular hub a fundamental methodological protocol for the future profession, inviting a reflection on how beauty can spring from a new and conscious ethics of limitation.

The genesis (data and methodology)

The intervention site is the former Tropicana complex in Rotterdam, a 12,000 m^2 structure that, since its inauguration in 1988, embodied the postmodern ideal of artificial entertainment: a tropical oasis under a geodesic dome, kept alive by an unsustainable energy metabolism and linear water management (Superuse Studios, 2017).

From "Urban Wreck" to "Material Bank"

With its final closure in 2010, the building had become an urban wreck, a critical mass of concrete, glass, and obsolete systems perceived as an obstacle to the development of the Maasboulevard. While the former ownership pressed for a clean slate to make way for standardized new residential blocks, Superuse Studios' intervention imposed an ontological reversal through Reverse Design. In this paradigm, the creative process is not triggered by an abstract functional program, but is subordinated to material availability and the residual potential of the existing structure. The design genesis is therefore the result of continuous negotiation between the spatial needs of the new occupants (circular start-ups) and the agency of the matter already present in situ.

The Investigation Methodology

Architectural due diligence did not simply address structural stability; it surveyed the quality of every metabolic flow, transforming technical restrictions into design opportunities:

· Heat Mapping and Thermal Mass:
The studio mapped the thermal storage capacity of the old concrete pools. Instead of demolishing them, they were preserved to act as natural temperature stabilizers. The residual heat still trapped in the underground systems was integrated into a local heating network (inter-company thermal exchange).

· "Zero-Kilometer" Urban Mining:
To bridge the building's material gaps without resorting to virgin supplies, the Harvest Map protocol was applied. Building waste streams were mapped within a 10 km radius, intercepting components (such as 7,000 m^2 of window frames from decommissioned offices) before they became waste.

· Envelope Diagnostics:
The geodesic dome, originally an energetic sieve, was reinterpreted as a buffer zone. The project did not attempt to climate-control the entire volume; instead, it inserted thermally isolated cells, drastically reducing the volume of air requiring treatment.

Internal Industrial Symbiosis

The fundamental transition in the design phase was the transformation of the concept of waste into a specific resource. BlueCity was designed as an Internal Industrial Symbiosis, where commercial activities coexist within a closed loop:

· Nutrient and Gas Cascade:
An operational example is the production of oyster mushrooms (cultivated on coffee grounds recovered from city cafes) within the former locker room areas. The CO_2 produced by the mushrooms' respiration, combined with the building's residual heat, can be utilized by other start-ups for the production of biomaterials or hydroponic crops.

· Closing the Water Cycle:
The hydraulic infrastructure of the former swimming pool was converted to house phytodepuration systems, allowing the reuse of greywater for internal production processes and reducing extraction from the municipal water grid by 60%.

The Architect's Role as "Financial Optimizer"

This procedure redefines the business model of the architectural studio. The designer acts as a flow mediator: they do not specify catalog products, but coordinate the extraction, diagnostics, and grafting of pre-existing components. This technique reduced material acquisition costs by 70%, reinvesting those resources into specialized labor and technological innovation, thereby guaranteeing the economic feasibility of an otherwise unsustainable operation.

BlueCity Protocol

The complex rises on the iconic skeleton of the former Tropicana tropical swimming pool. The specific intervention focused on the BlueCity Offices (a 1,300-square-meter portion created inside the wing that housed the old nightclub of the aquatic center) was carried out using a circular approach for 90% of the structural and finishing materials. This achievement cut CO_2 emissions by 68% compared to a traditional interior renovation (Superuse Studios, 2017).

01

Urban Mining and Digital Mapping

Superuse Studios' operational protocol is based on the use of the Oogstkaart ("Harvest Map"). This is a proprietary tool for geolocation and inventorying secondary raw materials available within a very tight territorial radius relative to the construction site:

· Solid Red Cedar Window Frames:
Interception and cataloging of hundreds of old glazed window frames removed during the renovation of a nearby residential complex in Rotterdam. The exotic wood frames were in excellent physical condition but geometrically heterogeneous.

· Metalwork and Steel Profiles:
Identification of structural beams, studs, and steel brackets recovered from local demolition sites, ready to be reused as the load-bearing skeleton for mezzanines and interior partitions.

· Furnishing Elements and Secondary Raw Materials In Situ:
Auditing of the interior materials within the former Tropicana, with the recovery of old concrete partition walls, portions of tiles, and wooden mooring dolphins (briccole) salvaged from the adjacent port area.

02

Toxicology screening and geometric classification

Given the extremely high reuse rate of reclaimed materials from uncontrolled demolitions, each component underwent verification to ensure its safe use in a high-density work environment:

· Remediation and Stripping of Wood Window Frames:
The Red Cedar frames were tested to detect old lead-based protective paints or non-compliant surface treatments. All approved components were mechanically stripped without the use of polluting chemical agents.

· Glass Diagnostics and Acoustic Resilience Testing:
The first glass panes of the windows were analyzed. Broken or cracked sheets were removed and replaced, while intact glass was classified by thickness to calculate the overall acoustic insulation coefficient of the future partition walls.

· Structural Inspection of Structural Metal:
The recycled metal beams and steel studs were brushed to remove surface oxidation and examined to rule out micro-cracks induced by previous mechanical dismantling operations.

03

Flexible industrialization and module expansion

To overcome the strong geometric heterogeneity of the recovered material, Superuse Studios forewent the forced adaptation of materials to a predefined design, choosing instead a design dictated by the dimensional availability of the waste:

· Sawtooth Partition Walls and Angled Composition:
Because the dimensions of the recovered window frames varied considerably in height and width, the architects assembled them in a zigzag (or sawtooth) arrangement. This three-dimensional geometric design allows the dimensional differences of the frames to be absorbed without cutting them, while stiffening the partition wall's self-supporting structure and eliminating the need for thick vertical studs.

· Integration of High-Performance Glulam Timber Frames:
In areas where the old windows did not reach the ceiling height of the former nightclub, the structure was compensated through integrating beams and studs made of certified and renewable European structural timber (new, but from an extremely short supply chain), serving as the primary containment framework.

04

Exceeding performance requirements

The project's compliance with Dutch building regulations (in particular regarding fire safety and thermo-acoustic comfort) required targeted adaptation approaches:

· The Regulatory Barrier of Fire-Rated Partitions:
Safety regulations prohibit the use of uncertified wood elements or those lacking a defined fire-resistance class for compartmentalizing main escape routes. Superuse Studios overcame this obstacle by organizing the floor plan so that the reclaimed wood walls served exclusively as internal partitions between adjacent offices or between offices and secondary corridors. The main load-bearing fire barriers and emergency stairs were instead treated with fire-resistant plasterboard and dry structural steel.

· Acoustic Comfort and Diffuse Lighting:
The angled orientation of the sawtooth glazed walls reduces internal acoustic reverberation in comparison to traditional coplanar walls. The total transparency of the modules allows light to penetrate deeply from the glazed facade facing the Meuse River into the interior distribution corridors, eliminating the need for daytime artificial lighting.

05 On-site waste integration

The BlueCity Offices construction site maximized the reuse of materials found directly inside the former tropical swimming pool, eliminating emissions associated with logistical transport:

· Navigation Dolphins Converted into Furnishings:
Massive load-bearing beams and wooden mooring posts, removed from neighboring quays and old water park installations, were cut and planed to create continuous desks, thick meeting tables, and the main reception counter.

· “Terrazzo” Flooring from Ceramic Rubble:
Tiles removed from the old pool basins and structural cement debris were crushed in situ. The colored ceramic fractions were used as exposed aggregate for the creation of new cement-based poured flooring, recreating the historical texture of the place without adding new extractive stone materials.

06 Design for Disassembly

The construction phase avoided any form of permanent or irreversible fixing, making certain that the entire office portion can be dismantled without producing waste should BlueCity’s spatial needs change:

· Interlocking Joints and Mechanical Seals:
The sawtooth walls made from the old window frames were secured to the floor and ceiling channels using wooden guide rails and elastic pressure gaskets, avoiding chemical glues or expanding polyurethane sealants. This ensures the intact recovery of individual window modules at the end of the offices’ lifecycle.

· Beeswax Finishes and Natural Paints:
The restored wood surfaces were treated exclusively with natural mineral oils and virgin beeswax, excluding the use of synthetic paints or glossy acrylic finishes that would compromise the wood’s natural reuse potential in future biological upcycling cycles.

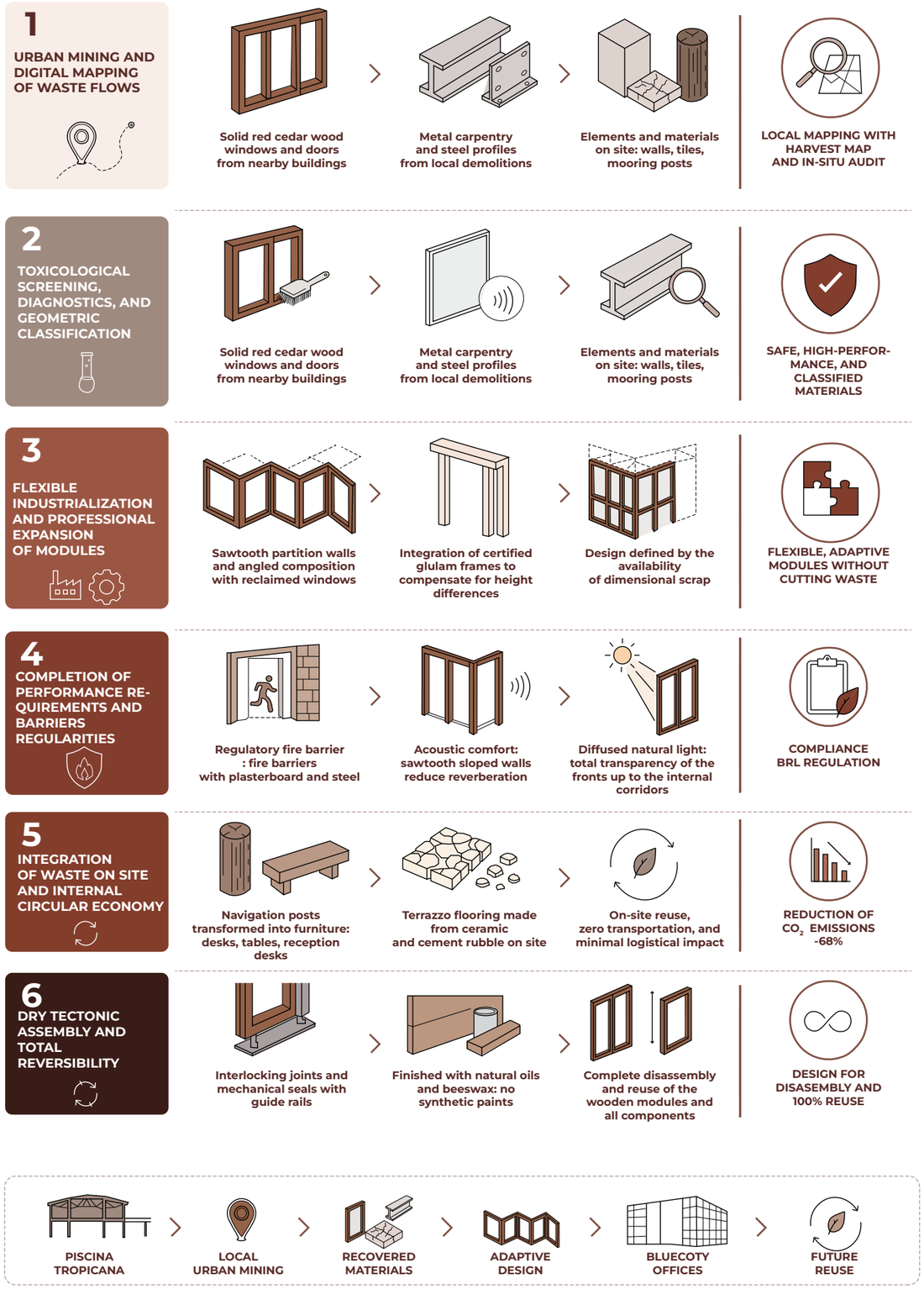


Fig. 62_BlueCity Offices Protocol. Source: *personal processing*

Quantitative analysis

The effectiveness of the operational protocol implemented in BlueCity lies not rstsolely in its ethical value, but in objective legitimation from data derived from rigorous monitoring of environmental and material performance. Through the application of advanced computationally-based tools, quantitative investigation shows how systemic upcycling is capable of overcoming the limits of conventional renovations, transforming resource savings into a parameter of financial and technical efficiency (Superuse Studios, 2017).

Material Circularity

The most significant data emerging from Superuse Studios' technical reporting concerns the circularity index, which reaches the threshold of 90% on the total mass of the new architectural components.

· Direct Reuse vs. Recycling:
This value was achieved by stressing direct reuse (component-to-component). To give an energetic dimension: reusing an aluminum window frame consumes only 5% of the energy required to remelt virgin material, preserving the added value of the first industrial processing.

· Critical Mass and Procurement:
The coordinated recovery of 7,000 m^2 of window frames and metal profiles prevented the introduction of 100 tons of virgin aluminum and steel onto the market, rendering the project immune to raw material price fluctuations.

· Asset Compliance:
This percentage positions BlueCity as a reference for EU Regulation 2020/852 (Green Taxonomy), guaranteeing the property access to subsidized financing linked to ESG criteria.

CO_2 Reduction: The Impact on Embodied Carbon

The Life Cycle Assessment (LCA), focused on modules A1–A3 (extraction and production), highlights a 68% reduction in embodied CO_2 emissions.

· Partition Efficiency:
While a standard partition wall made of new glass and aluminum generates approximately 45–60 kg CO_2/m^2, BlueCity's "patchwork" solutions reduce the impact to under 15 kg CO_2/m^2. This differential is due to the total elimination of energy-intensive melting processes.

· Data Certification:
The use of One Click LCA software and the Dutch NMD (National Environmental Database) grants the project scientific validation that transforms environmental savings into a reputational and regulatory asset.

Zero Waste Strategy

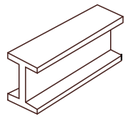
The BlueCity construction site was managed as a closed-loop system, where 95% of processing waste was reintroduced into the production cycle.

· Micro-Upcycling and Symbiosis:
Metal and glass scraps were used for construction details (signage, handles), while 100% of wood and organic waste was transferred to internal start-ups (e.g., RotterZwam) as a substrate for mushroom cultivation or the development of biomaterials.

· Economic Advantage:
This management almost entirely eliminated logistics costs to landfills and the related special waste disposal taxes, which usually account for a significant share of construction site overhead.

Quantitative estimate

Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



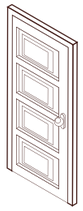
250 TONS STEEL

BEFORE: Former metal structures
AFTER: Custom-made structure and furnishings



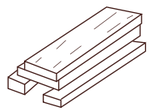
180 m^2 GLASS

BEFORE: Former windows and facades
AFTER: Interior glass walls



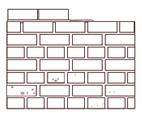
120 DOORS WOOD

BEFORE: Residential and office buildings
AFTER: Interior doors



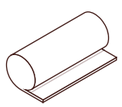
320 m^2 WOOD

BEFORE: Flooring and beams
AFTER: Cladding, furnishings, and panels



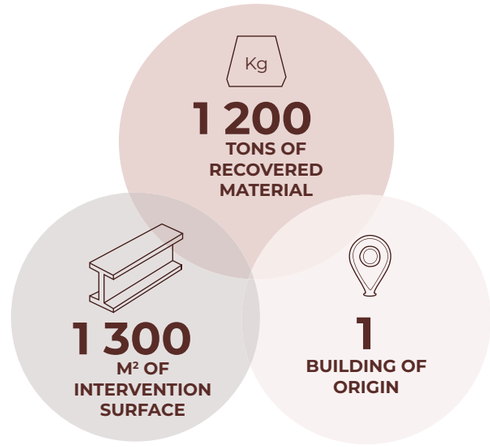
15 000 BRICKS AND STONES

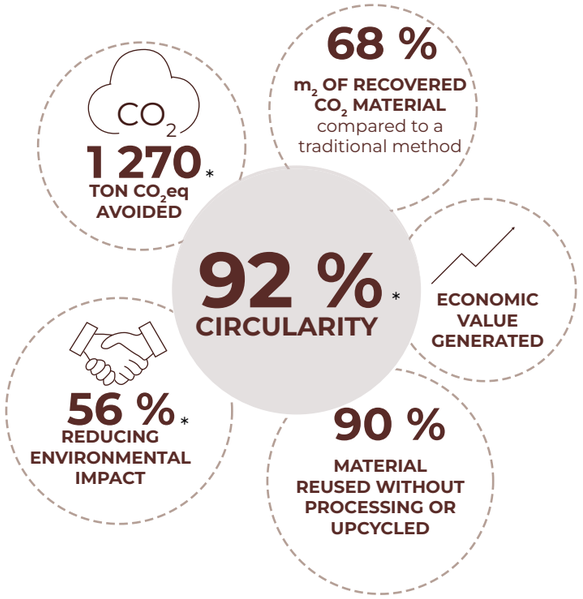
BEFORE: Historic buildings and demolitions
AFTER: Paving and details



600 m^2 INSULATING

BEFORE: Recycled insulation materials
AFTER: Thermal and acoustic insulation





* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 63_Quantitative analysis of BlueCity Offices. Source: personal processing

Economic analysis

The economic analysis of the BlueCity project definitively dismantles the academic and vocational prejudice that architectural upcycling is an elite practice destined to remain confined to isolated experimentation due to unsustainable costs. On the contrary, the financial balance sheet of the intervention demonstrates how the transition toward a circular model allows for the complete reconfiguration of the cost structure, converting traditional expenditure items (material purchases) into investments with high added value (local skills and labor) (Superuse Studios, 2017).

Budget Redistribution

A key finding from Superuse Studios' cost analysis concerns variation in internal financial flows on the construction site (CapEx). In a traditional project, the majority of the budget is allocated to the purchase of industrially produced virgin materials, while labor is often viewed as an item to be optimized.

· Inversion of Spending Dynamics:
At BlueCity, specialized labor costs (necessary for diagnostics, selective dismantling at donor buildings, logistical transport, and artisanal adaptation in situ) were 15–20% higher than in a conventional construction site.

· Compensation via Harvesting:
This increase was amply compensated by a 70% reduction in material acquisition costs. By intercepting components that represented a disposal burden for the transferring owner, the procurement of high-performance elements (thermal-break window frames, steel beams) took place solely at the cost of logistics.

· The "Tax Shift":
This operation shifts financial capital from the global extractive industry toward the local economy, remunerating technical expertise rather than the consumption of new matter. This model anticipates policies shifting taxation from resources to labor.

The Economic Value of Industrial Symbiosis and "Circular Rent"

Beyond savings during the construction phase, BlueCity introduced a new value chain in the operational management of the property (OpEx), increasing post-intervention profitability through the "Circular Rent" model.

· Reduction of Operating Costs:
Integrated flow management (heat and water sharing, organic waste recovery) drastically reduces operating expenses for every occupant. The building operates as a network where one start-up's waste becomes raw material for another.

· Attractiveness for "Green Tenants":
The ready-to-use circular infrastructure attracts tenants willing to pay a premium on rent (Circular Rent) in exchange for ecosystem benefits and a reduction in their own disposal expenses.

· Hedge Against Volatility:
By utilizing materials already present within the economic cycle, the project is shielded from price fluctuations of virgin raw materials and global supply chain crises.

Marketing of Authenticity and Access to ESG Capital

Finally, economic analysis must consider the impact on asset value within the context of contemporary sustainable finance.

· Marketing of Authenticity:
The aesthetics of upcycling, defined by Superuse as conscious beauty, transformed a former urban wreck into a global icon, increasing the visibility and prestige of the real estate asset.

· ESG Rating and Green Taxonomy:
This positioning allowed BlueCity to fit perfectly with the criteria of the European Union's Green Taxonomy. The property thus gained access to subsidized credit lines and institutional investors interested in portfolios characterized by low climate risk and high social impact.



Fig. 64_Component origin analysis in the BlueCity Offices project. Source: Personal processing from *superuse-studios.com*

Problems and Successes: Lesson Learned

The Challenge of Normative Asynchrony

The most difficult challenge involved the performance certification of over 7,000 m^2 of reclaimed window frames sourced from various origins (Superuse Studios, 2017):

• Fire Resistance and Static Safety:
Certifying the reaction to fire of components from different eras and manufacturers, often lacking original technical documentation and CE marking, required a radical paradigm shift. Unable to rely on catalog certifications, the team had to implement unconventional on-site testing and ad hoc engineering simulations to validate the safety of collage assemblies. This entailed a constant and often arduous dialogue with firefighters and certifying authorities, preparing the path for future validation protocols for reuse.

• Acoustic and Thermal Performance Throughout Uncertainty:
The variation in glass thicknesses and the condition of the original one-seal made uniform performance guarantees impossible. Overcoming this impasse occurred through technical negotiation: it was demonstrated that system performance (the partition wall in its entirety) can compensate for the shortcomings of the individual component through redundant construction details and additional gaskets, guaranteeing legal requirements are fulfilled without resorting to material replacement.

Methodological Success

The most significant success of BlueCity lies in redefining the architect's professional role in the 21st century. The project demonstrates that the designer can and must evolve from a mere prescriber of prefabricated products to a manager of material and energy flows. Superuse Studios has shown that it is possible to disrupt the rigidity of industrial catalogs through a deep knowledge of urban logistics and material diagnostics.

Achieving a 90% circularity threshold in such an antagonistic regulatory context represents a systemic victory: it is proof that upcycling is not simply an aesthetic choice or an isolated ethical stance, but a legitimized technical practice. The architect becomes the pivot of a new supply chain that unites selective demolition, recovery logistics, and adaptive design, transforming the intrinsic uncertainty of the urban mine into a controlled and secure design resource.

The Lesson Learned: Towards an Aesthetics of Heterogeneous Harmony

The fundamental lesson that BlueCity bequeaths to architectural discipline concerns the definitive overcoming of the modernist dogma of modular perfection and flawless seriality. The project teaches that beauty no longer resides in industrial uniformity or the repetition of a perfect module, but in the technical capacity to harmonize the heterogeneous.

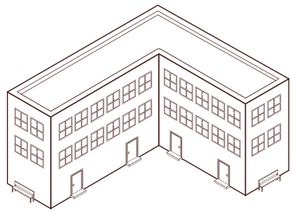
BlueCity's architecture celebrates the sincerity of the reclaimed material, in which each scratch on the paint of the profiles or every chromatic variation of the frames tells a story of energy conservation and temporal value. The lesson learned is that radical sustainability requires a new aesthetic canon: a tectonics of the fragment where design quality is not evaluated by the ability to hide joints, but by the capacity to transform the obsolescence and disorder of the urban mine into a new, conscious, and resilient spatial order. Ultimately, BlueCity demonstrates that real sustainable beauty comes from the creative resolution of the conflict between the rigidity of the norm and the vitality of waste, offering an operational protocol for an architecture that does not fear time, but uses it as a building material.



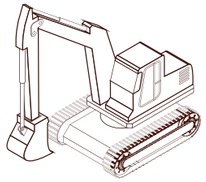


Fig. 65_Photographs of the BlueCity Offices construction site. Source: *superuse-studios.com*

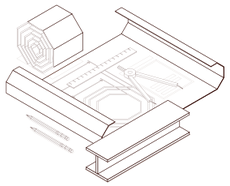
SYNTHESIS



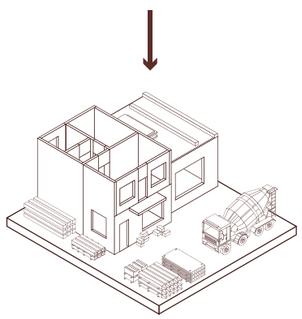
EXISTING BUILDING



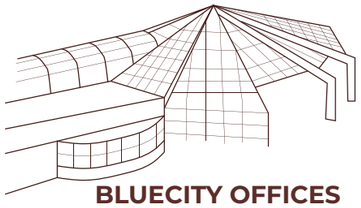
URBAN MINING



DIAGNOSTICS



DESIGN FOR DISASSEMBLY



BLUECITY OFFICES

-1 270 t *

CO_2 eq. avoided

-38 % *

total cost

-90 % *

waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 66_Summary diagram of the BlueCity Offices project. Source: *personal processing*

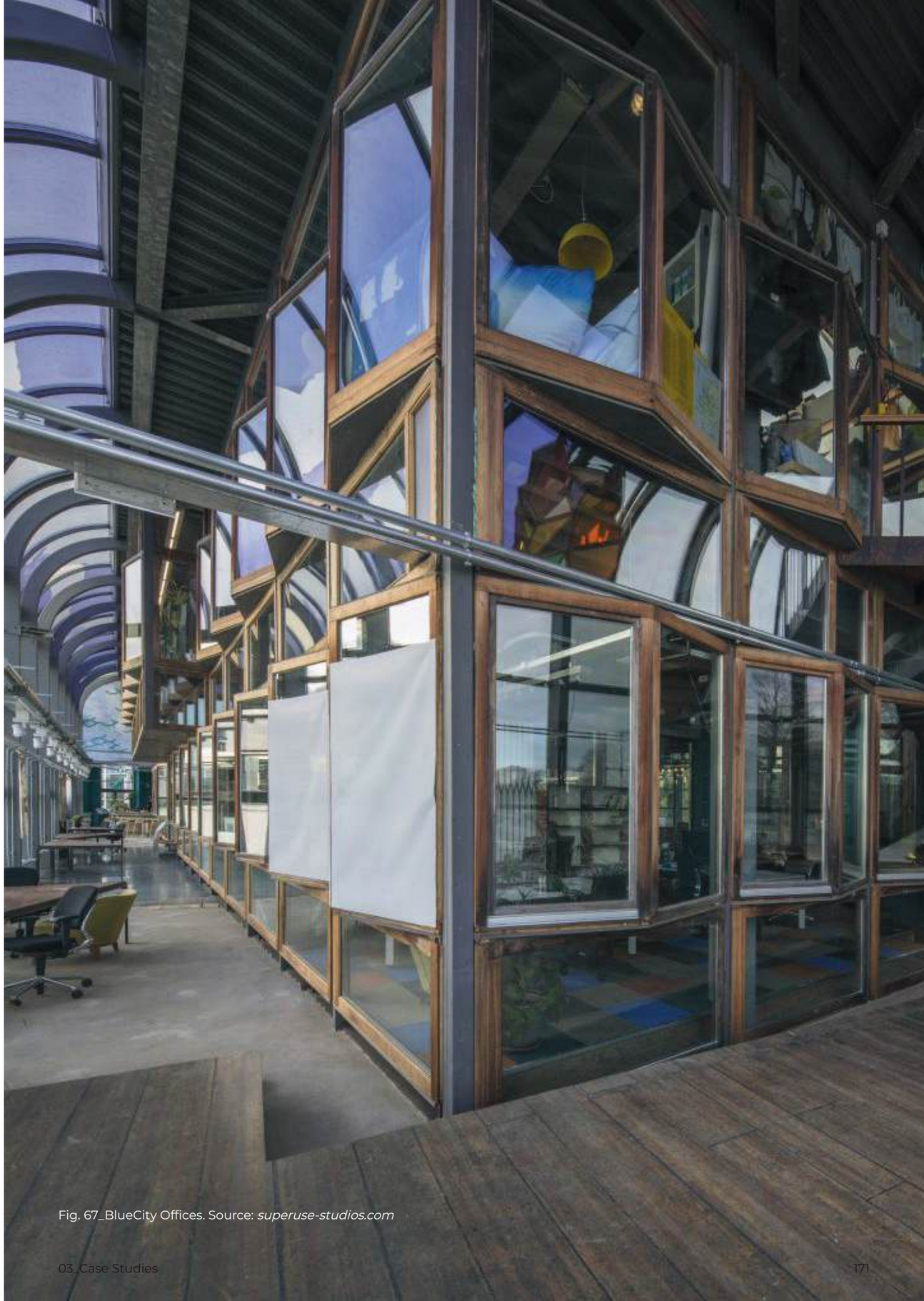


Fig. 67_BlueCity Offices. Source: *superuse-studios.com*

Tangenkaia Harbor

Designer:
SLA

Client:
Tangenkaia Eiendom AS

Site:
Drammen, Norway (100 000 m²)

Year:
2020

Size L

Urban context |
Large-scale building



Fig. 54 Tangenkaia Harbor - SLA, Drammen, 2020. Source: *sla.dk*

The Tangenkaia Harbor project in Drammen, developed by the SLA studio, radically shifts the horizon of research toward a systemic and territorial scale (SLA, 2020). In this experience, the concept of recovery goes beyond the boundaries of the building envelope to include the soil, port infrastructure, and horizontal industrial residues, reconfiguring the landscape as an active catalyst of pre-existing resources.

Tangenkaia acts as a methodological manifesto of how landscape architecture can act as a device for circular urban metabolism. SLA transforms an obsolete port area, defined by decades of heavy logistics, into a strong and energetic urban district, where 100% of the visual and functional identity does not derive from a new formal imposition or the importation of alien styles, but springs directly from the creative, technical, and planned reuse of what was already present on the site.

SLA's approach breaks the conventional practice of port tabula rasa, which typically entails comprehensive remediation and the mechanical removal of every previous anthropogenic layer to make way for new real estate developments. On the contrary, the project adopts a methodology of "Horizontal Urban Mining": broken concrete, rusted railway tracks, mooring bollards, and even mineral deposits cease to be considered liabilities or waste to be disposed of in landfills. They are elevated to fundamental components of the new public space.

Through a practice of soil surgery that focuses on selective de-paving and the embedding of Nature-based Solutions (NbS), Tangenkaia demonstrates that real sustainability in the 21st century lies in the capacity to reactivate the unexpressed potential of infrastructural residue. This process makes it possible to transform the marks of a productive past into devices for ecological robustness (water management, enhancement of urban biodiversity) and collective memory, delivering a concrete response to the need to reduce the embodied carbon footprint in large urban transformation interventions. The port, ceases to be a decommissioned logistic machine to become a living laboratory of circular regeneration.

The genesis (data and methodology)

The regeneration of Tangenkaia, promoted by the municipality of Drammen, embodies a fundamental paradigm shift in the treatment of brownfield areas. The main challenge was transforming an obsolete industrial port into a contemporary urban district, while refraining from the tabula rasa approach that typically characterizes European waterfronts. SLA responded with a Landscape Archaeology approach, where the productive past is not a constraint to be masked, but rather the primary construction material, both in physical and ecological terms (SLA, 2020).

The "AS-IS" Methodology

SLA's methodological innovation consists in expanding the concept of Urban Mining into the horizontal dimension. While traditional urban planning treats industrial soil as a "dead" surface to be leveled and waterproofed ex novo, the "AS-IS" methodology treats it as a stratigraphic and material asset.

· Millimetric Material Survey:
The project started with a systematic survey of textures: worn asphalt, railway tracks embedded in concrete, prestressed concrete slabs, and cast-iron bollards. Each element was cataloged not by its state of preservation, but for its ability for refunctionalization.

· Valorization of the Defect:
Instead of removing deteriorated pavements, SLA identified the port's cracks and fissures as design opportunities. These wounds in the soil become the points of insertion for the new ecological infrastructure. Through selective de-paving, the studio determined where to open the ground to promote permeability while maintaining the aesthetics of the existing site.

Environmental Data

The project's effectiveness is validated by a drastic reduction in embodied carbon, a parameter that SLA establishes as the foundation for the economic and environmental feasibility of the work.

· 60% CO_2 Reduction:
Compared to the creation of a traditional urban park (which would require soil excavation, the transport of aggregates to landfills, and the importation of natural stone or new concrete), Tangenkaia cuts the carbon footprint by over 60%.

· Closed-Loop In Situ:
By avoiding the extraction and transport of stone materials (frequently sourced from extra-European quarries with high carbon intensity), the project minimizes grey energy. The existing soil acts as a warehouse of raw materials: the asphalt fragments removed to create flowerbeds are crushed and reused in situ as a draining substrate or mineral mulch, eliminating special waste disposal costs.

Biodiversity

The concept of recovery at Tangenkaia does not stop at inanimate matter, but includes the pre-existing biological component.

· Botanical Census of Pioneer Flora:
Instead of proceeding with standard plant clearance, SLA's botanists cataloged spontaneous species that emerged between the port's fissures during the years of decline. These species are, in fact, extremely resilient organisms already adapted to the port's windiness, the salinity of the air, and the presence of pollutants in the soil.

· Design-by-Seeding:
These pioneer plants were integrated into the new design. Vegetation is no longer confined to fixed flowerbeds, but is allowed to freely colonize infrastructural voids. This approach ensures:

· Near-Zero Maintenance Costs:
The species are autonomous and do not require artificial irrigation.

· Climate Resilience:
A vegetative cover that requires no fertilizers and actively contributes to mitigating the city heat island effect without the input of new water resources.

Tangenkaia Protocol

The urban regeneration project for Tangenkaia Harbor in Drammen (Norway), developed by the landscape architecture studio SLA in collaboration with Add Arkitekter, DRMA, and local partners, redefines the transition of a 10-hectare former industrial port into a strong, bioclimatic coastal district.

To overcome the rigidity of traditional long-term planning processes and valorize the site's industrial archaeology, the consortium codified a protocol of circular urbanism and incremental activation, integrating social co-design, ultra-short-supply-chain local material recovery, and nature-based solutions (SLA, 2020).

01 Ecological, social, and material mapping

The protocol begins with an in-depth investigation intended at mapping physical resources, latent ecology, and the community structure of the former port area along the Drammenselva River before definitive masterplan construction sites commence:

· The Decommissioned Infrastructural Heritage:
Cataloging historic railway tracks (Tangensporet), concrete quays, and existing industrial warehouses (such as the Skur 3 and Skur 4 hangars), evaluating their potential as elements of morphological and identity continuity.

· Mapping of Urban Material Flows:
Tracking active demolition and renovation sites within the municipal radius of Drammen to identify streams of "noble waste" to be intercepted prior to landfill disposal.

· Analysis of Local Micro-Communities:
Direct involvement of residents, schools, and local stakeholders to understand recreational needs and identify priority areas for public access to the riverfront.

02 Characterization of local secondary raw materials

The team isolated and collected heterogeneous reclaimed materials sourced directly from the site or from urban retrofit operations in the immediate vicinity, standardizing their performance:

· Facade Panels from Bragernes Torg 1:
Decommissioned facade slabs and modules from the renovation of an office building in the nearby city center, selected for use as partition and protective elements in public spaces.

· Subsurface Excavation Boulders and Logistics Concrete Blocks:
Large limestone rocks unearthed in situ during infrastructural excavation work and concrete pipes or barriers decommissioned from past port logistics activities, tested to ensure geotechnical stability and the absence of industrial contaminants.

· Topsoil and Local Pioneer Flora:
Identification of natural riverbed soil and spontaneous herbaceous species that emerged on the quays, to exploit the biological strength of native vegetation ("City Nature") adapted to the river's flood dynamics.

03 Transitional co-design and low-impact activation

Social integration and the pre-figuration of the future district were guided by a series of practical workshops that used reclaimed materials as tools for visual and spatial communication:

· Community Self-Construction Workshops:
Utilizing discarded port materials to co-design and assemble temporary urban furnishings, workshop pavilions, and event stages, permitting citizens to experience and test future uses of common areas in real time.

· Collective Planting and Biodiversity Education:
Active involvement of local school students in bulb and nectar-producing plant campaigns, creating temporary micro-ecological oases and building a strong sense of place attachment and stewardship.

04 Soft mobility routes

The physical reconnection of the former port with the city was anchored by a linear soft mobility axis and a linear activity park designed while limiting the use of new mineral resources:

· Conversion of Port Railway Tracks:
The old freight railway line was partially cleared and integrated into a new continuous pedestrian-cycle path, preserving the historic mineral texture.

· Flexible-Modularity Activity Park:
The large excavation boulders and recovered concrete pipes were distributed along the path and anchored by gravity to form seating areas, playful climbing elements for children, skate parks, and a central fire pit area. This arrangement avoided purchasing catalog equipment with a high carbon footprint.

05 Adaptive strategy of “City Nature”

Instead of designing rigid barriers against rising water levels and stormwater management, SLA developed an adaptive and multifunctional blue-green infrastructure:

· Sustainable Water Drainage Systems (SuDS):
Design of infiltration trenches, rain gardens, and depressed areas that locally collect, filter, and manage rainwater, lessening the risk of surface flooding.

· Biological Inoculation of Quays:
Making use of the porosity of reclaimed materials used for new paving (such as rock boulders arranged along the water’s edge), spontaneous colonization by aquatic plants and insects was fostered, increasing riverbed biodiversity from the earliest development stages.

06 Tectonic reversibility

The urban furnishing elements, manufactured during the installation phase, were engineered according to strict criteria of dimensional and material reversibility:

· Mechanical Fastenings and Absence of Cast Foundations:
Reclaimed facade panels from Bragernes Torg 1 and structural concrete blocks were dry-assembled using bolted metal plates, avoiding cementitious binders or invasive excavation.

· End-of-Cycle Reuse Logistics:
At the end of the transitional period, when the stable construction phases of the masterplan begin, the entire inventory of materials (rocks, wooden furnishings, metal panels) can be fully dry-disassembled. These parts will subsequently be re-integrated into the permanent green areas of the new district, eliminating construction site waste generation and retaining the carbon stored within the urban lifecycle for decades to come.

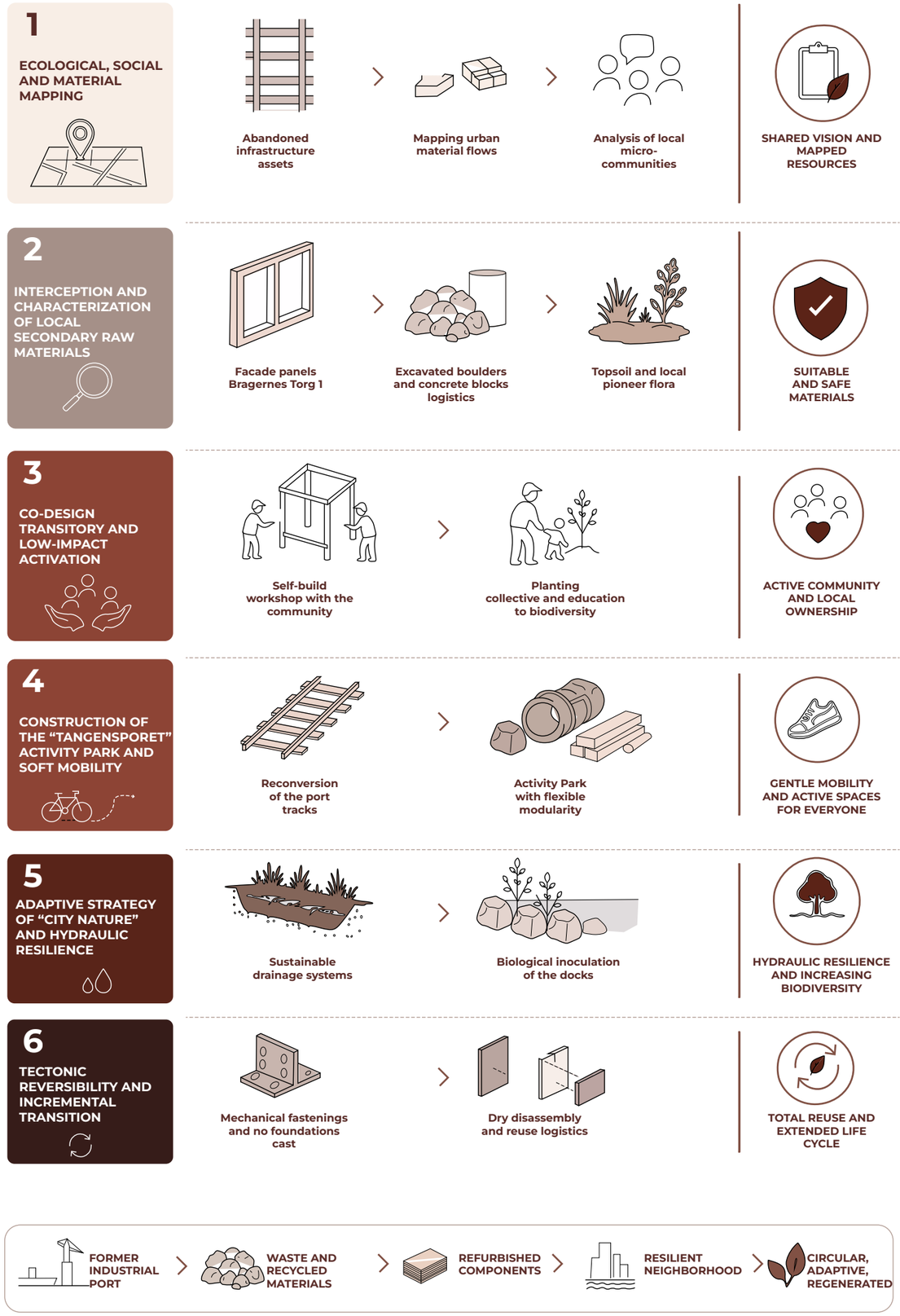


Fig. 55_Tangenkaia Protocol. Source: *personal processing*

Quantitative analysis

The empirical confirmation of the SLA model is found in its capability to translate the poetic vision of recovery into unassailable metric data. This section dissects the district's performance among three fundamental axes: hydrology, structural mass, and material lifecycle (SLA, 2020).

Permeable Surfaces

In a port context, waterproofing is historically close to 100%. The project radically reversed this trend, transforming the sealed soil into a sponge infrastructure.
Permeability increased by 150% compared to the original industrial configuration. SLA used the technique of "surgical punching": by removing strategic portions of asphalt and using recovered crushed stone as a porous sub-base, a bio-retention system was created.
The area is now capable of managing the runoff of extreme weather events directly in situ. This reduces the instantaneous load on the municipal sewage network by 40%.

Structural Reuse

The most impactful decision in terms of avoided emissions concerns maintaining existing volumes, reversing the logic of the traditional real estate market that favors demolition for site clearance.
75% of the pre-existing port volumes were preserved and refunctionalized.
Keeping these structures avoided the disposal of thousands of cubic meters of reinforced concrete. Considering that cement is responsible for about 8% of global CO_2 emissions, preserving the structure enabled the freezing of carbon emitted decades ago.
This approach generated an estimated saving of approximately 3,500 tons of CO_2. To make this data comprehensible to the client, it is the equivalent of the annual emissions of over 700 passenger cars removed from the road for an entire year.

Local Materials

The Tangenkaia project acts as a driver of a hyper-local circular economy, where the construction site itself becomes the factory for its furnishing components.
90% of the furnishing elements (benches, lighting systems, bollards) are made via in-situ upcycling.

Internal Supply Chain Analysis:

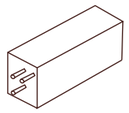
• Reclaimed Wood:
Old railway sleepers and structural beams from minor warehouse demolitions were planed, treated with natural oils, and reassembled into ergonomic seating.

• Industrial Metals:
Parapets and supports for climbing vegetation were created by refitting or reassembling steel and cast iron sourced from old cranes and dismantled non-structural parts.

This strategy eliminated the grey energy linked to the transport (often international) of catalog urban furniture components, while simultaneously guaranteeing a unique and unrepeatable aesthetic.

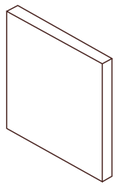
Quantitative estimate

Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



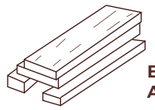
1 850 BLOCKS REINFORCED C.

BEFORE: Existing docks and piers
AFTER: Steps, seats



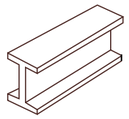
2 400 m² STONES

BEFORE: Former port pavement
AFTER: Paving and paths



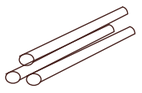
780 BOARDS WOOD

BEFORE: Former wooden structures and piers
AFTER: Furnishings and railings



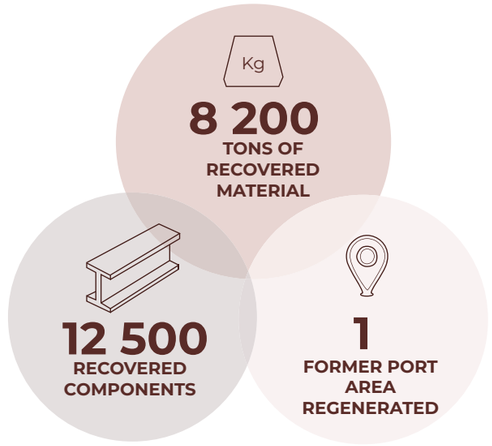
1 000 BEAMS STEEL

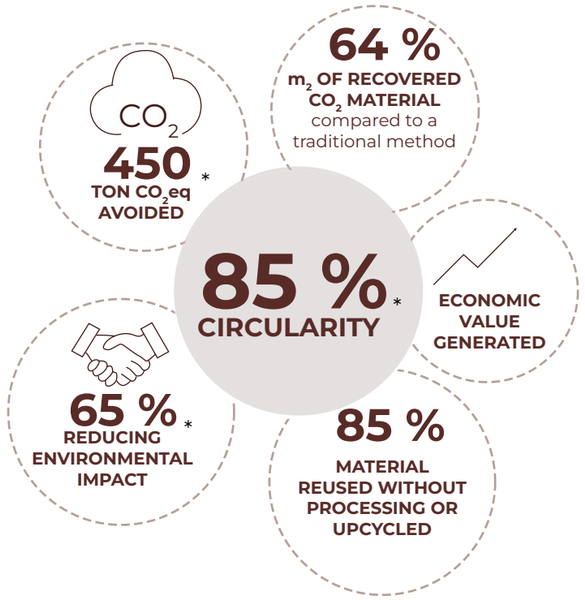
BEFORE: Disused tracks and structures
AFTER: Furnishing elements and protections



260 PROFILS STEEL

BEFORE: Port poles and moorings
AFTER: Lighting and signage





* Value estimated through AI support through comparative analysis between the upcycled process and traditional demolition

Fig. 56_Quantitative analysis by Tangenkaia. Source: personal processing

Economic analysis

The economic analysis of Tangenkaia overturns the traditional paradigm that remediation of a decommissioned industrial area is inherently more expensive than ex-novo construction. The SLA studio demonstrated how a circular management of the site allows for a budget shift: funds that are usually dispersed in passive and destructive items are reinvested in architectural quality and ecological regeneration (SLA, 2020).

Avoided Costs

In a traditional industrial waterfront, remediation, demolition, and site preparation works can absorb between 30% and 50% of the total intervention budget. At Tangenkaia, this financial hemorrhage was drastically contained.

• 30% Savings on Construction Site Costs:
This saving stems primarily from having avoided massive earthmoving and deep excavation. In port sites, soils are often classified as potentially contaminated by hydrocarbons or heavy metals; removing, transporting, and disposing of them requires special procedures and prohibitive landfill fees.

• Stabilization and In Situ Capping:
Instead of excavating the contaminated soil, SLA opted for stabilization and selective coverage techniques using the site's own recovered crushed material. This strategy canceled logistics costs and special waste disposal charges, converting what was an environmental liability into a solid and certified base for the new district.

Investment in Design and Natural Capital

The savings achieved on raw materials and supply chain were not subtracted from the value of the work, but were deliberately reinvested to increase the performance and attractiveness of the project.

• From "Gray" to "Blue-Green" Infrastructure:
Funds saved on the purchase of virgin concrete and imported natural stone were diverted toward sophisticated phytodepuration systems and nature-based engineering. This made it possible to create a stormwater management infrastructure that is more durable and less costly in terms of future servicing compared to a standard mechanical sewage network.

• Nobilitation of Waste:
Because the raw material (asphalt, poles, tracks) was free of charge, the budget was invested in the specialized labor required to process them. Transforming a degraded bollard into an ergonomic seat requires more design than purchasing a catalog bench; however, the final cost is offset by the avoided purchase of the industrial product and the added value of a unique, custom-made piece.

Branding Effect

The most important economic success does not lie in savings during construction, but in the market attraction capacity generated by the uniqueness of the site.

• The Identity Premium:
In a real estate market often saturated by aseptic, soulless neighborhoods, Tangenkaia's port aesthetic generated an immediate brand identity. Preserving the traces of time serves as a guarantee of cultural authenticity, a factor that high-profile residential and commercial segments actively seek today.

• Increase in Real Estate Value (+25%):
The market rewarded the choice: the value of surrounding properties and units under design increased by 25% even before the completion of the works. Tangenkaia is not perceived as an economic recovery zone, but as an elite destination, demonstrating that industrial history is a financial asset capable of accelerating the absorption of real estate units on the market.

ORIGIN OF COMPONENTS



Fig. 57_Component origin analysis for the Tangenkaia Harbor project. Source: personal processing from sla.dk

Problems and Successes: Lesson Learned

The SLA studio demonstrated that those bureaucratic and technical barriers, when addressed with a multidisciplinary approach, can become the pillars upon which to build a project's uniqueness (SLA, 2020).

The Regulatory Problem

Port and industrial soils, such as those in Drammen (or the former Fiat areas in Turin), bear the marks of decades of heavy logistical activity. The presence of hydrocarbons, heavy metals (lead, zinc, cadmium), and bituminous residues often turns the site into a bureaucratic landmine.

· The Legislative Conflict:
National regulations frequently impose virgin soil standards for residential conversions, making total removal (dig-and-dump) the only apparently safe path. Reusing material in situ is perceived as a legal and health risk, discouraging investors because of possible long-term civil liability.

· The Technical Obstacle:
Industrial concrete and asphalt are not pure materials; their crushing can release previously sealed dust or pollutants, calling for rigorous and costly surveillance procedures.

The Solution: Phyto-Remediation

SLA overcame the regulatory impasse by adopting a flexible and biological approach, replacing instantaneous mechanical remediation with phyto-remediation (or phyto-depuration).

· The Strategy of "Hyper-Accumulator" Species:
Instead of hiding the problem beneath a new concrete sub-base, specific plant species were planted (such as varieties of willows, poplars, and pioneer grasses) capable of extracting, degrading, or stabilizing contaminants in the soil through their root systems and the microbial activity of the rhizosphere.

· Remediation as an Educational Performance:
The site was gradually opened to the public. The soil healing process was not hidden behind construction fences, but became part of the urban experience. Through educational signage, citizens were able to observe nature as it metabolized the industrial past, transforming a technical operation into an act of collective care for the territory and increasing the transparency of the process.

Social Success

One of the greatest risks of new waterfront developments is rejection by the local population, who often see such interventions as aseptic gentrification that erases working-class identity.

· Maintenance of the Emotional Bond:
By preserving rough textures, railway tracks, and old quays, SLA created a landscape that does not feel imposed from above, but rather organically evolved. Success lies in having avoided the brand-new effect, preferring an imperfect beauty which echoes with the historical memory of Drammen.

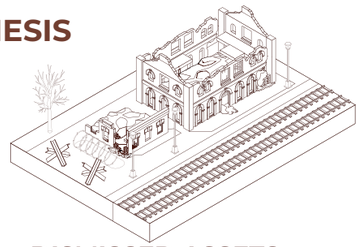
· Social License to Operate:
This approach drastically reduced local opposition. The community did not perceive the end of its productive history, but rather its metamorphosis into a new form of public value. The district became a place even before being completed, guaranteeing the commercial success of the operation thanks to a user base already emotionally attached to the site.





Fig. 58_Photographs of the Tangenkaia Harbor project construction site. Source: *sla.dk*

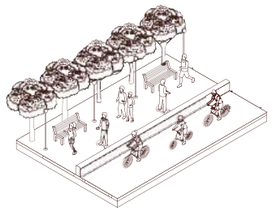
SYNTHESIS



DISMISSED ASSETS



CO-DESIGN



GENTLE MOBILITY



REVERSIBILITY'



TANGENKAIA HARBOR

-450 t *

CO_2 eq. avoided

-34 % *

total cost

-90 % *

waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 59_Tangenkaia Harbor project summary diagram. Source: *personal processing*

Fig. 60_Tangenkaia Harbor. Fonte: *sla.dk*

The Waterfront Neighbourhood Space

Designer:
GXN - 3XN

Clients:
Waterfront Toronto, C40 Cities, and the City of Toronto

Site:
Toronto, Canada (3 909 m²)

Year:
2026

Size S
Pavillon

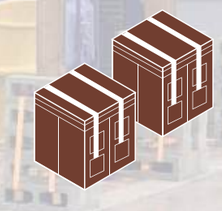


Fig. 68_The Waterfront Neighbourhood Space - GXN- 3XN, Toronto, 2026. Source: *gxn.3xn.com*

The Waterfront Neighbourhood Space by GXN and Waterfront Toronto acts as an international manifesto of circular civic design and social resilience. Although located outside the European context, this project constitutes an essential piece to understand the global scope of upcycling: it demonstrates how the basic principles of circularity developed within the European architectural debate (primarily from Danish design culture) can transcend local regulatory boundaries to become an exportable and universal paradigm (GXN, 2026).

GXN dismantles the linear logic of temporary installations and traditional public space, transforming the construction site into a laboratory for valorizing local resources.

The choice to include this case study within the research is based on its ability to show the evolution of upcycling on an international scale: no longer simply a response to strict landfill taxes or community energy restrictions typical of the Old Continent, but an ethical and design response to the global climate crisis, capable of cutting the carbon footprint via a strong bond with the territory.

The project introduces three fundamental methodological advances to the discipline:

1. Territorial Urban Mining:
In the Waterfront Neighbourhood Space, material procurement does not follow the logics of global industrial supply chains. The raw material stems from the systematic mapping of waste present in the Toronto metropolitan area (from demolished churches to road construction sites), transforming the design approach into a curation of material memories and local flows.

2. The Aesthetics of Variability:
The project tackles the most difficult challenge of reclaimed material: dimensional and physical irregularity. Rather than imposing a standardized geometry, the team designed through adopting tolerance and variability, demonstrating that the most resilient construction details are those capable of adapting to the intrinsic nature of the waste.

3. The “Stacked and Strapped” Kit:
Instead of resorting to glues or permanent pours that condemn materials to downcycling, GXN devised a construction system based on stacking and mechanical tensioning. This intuition transforms temporary architecture into a totally reversible structure, in which every component can be disassembled and reused indefinitely.

The Waterfront Neighbourhood Space is therefore not just a temporary civic installation, but a mature and replicable model of circular economy. It demonstrates that urban waste, if accurately mapped and managed, possesses extraordinary cultural and ecological value, capable of generating high-quality public spaces without consuming new untouched resources.

The Genesis (dates and methodology)

The Waterfront Neighbourhood Space project did not originate as a conventional urban regeneration operation or a simple public furniture arrangement; rather, it was conceived as a strategic, targeted response to the need to reconnect a decommissioned area through the radical valorization of local material heritage. For the designers, decreasing environmental impact, controlling emissions, and preserving the memory of the place became rigorous practical priorities, placed on the same level as traditional financial parameters and construction costs (GXN, 2026).

• Regeneration as an Urban Strategy
Within the intervention context, guidelines for sustainability and resource management mandate a drastic reduction in demolition waste disposed of in landfills and a strict limit on the carbon footprint generated by new interventions. Demolishing current structures and rebuilding ex novo entirely would have entailed unsustainable energy consumption and the definitive loss of the area’s historical and layered port identity.

The adopted methodology demonstrated that, starting from a systematic inventory of existing structures, the budget of grey energy and embodied carbon could be preserved rather than dispersed, being reinvested to give life to a new public and collective space with high climate and social resilience.

• Material Survey and Cataloging
The studio did not rely solely on historical floor plans or archival documents, which are often incomplete or altered by successive stratifications. The entire area was mapped and digitized to thoroughly understand the conservation status of present structures and the actual consistency of recoverable building components.

Before defining the new design of the public space, a geolocalized inventory of available materials was drawn up, a sort of urban matter passport. This made it possible to simulate the reuse of building components directly on-site, precisely identifying which structural, metal, or finishing elements possessed the load-bearing capacity, durability, and aesthetic characteristics necessary for a second life within the new project.

• Component Engineering
One of the most innovative aspects of the intervention concerns the treatment, selection, and relocation of decommissioned construction elements. Instead of proceeding with summary demolitions and crushing existing artifacts into low-value aggregates for road sub-bases (downcycling), stone, wood, and metal components were selectively dismantled, cleaned, and recontextualized in space.

The extracted materials underwent testing to verify their mechanical performance, resistance to atmospheric agents, and adherence to current regulations. Many of these items were skillfully reused to create new drainage pavements, containment walls, integrated public seating, and support structures for urban greenery, radically transforming the perception and functionality of the public space without resorting to the extraction and purchase of virgin raw materials.

• Timelines and Design
During the preliminary phases of analysis, auditing, and cataloging, the designers conducted targeted technical and environmental verifications on the recovered materials, validating their compliance through empirical data and focused testing.

The adopted approach demonstrates that upcycling-based design requires an initial investment of time dedicated to listening to the place and mapping resources—time that is nevertheless amply repaid by the elimination of disposal costs, the drastic reduction of the ecological footprint, and the creation of an authentic architectural and landscape language strongly rooted in the industrial and material history of the context.

Waterfront Neighbourhood Space Protocol

Born as a civic space and temporary gathering place to support community, social life, and daily activities, the intervention completely overturns the conventional construction process: rather than proceeding according to the linear “design-then-buy” model, the team started a workflow guided by the availability, in-depth analysis, and preventive mapping of waste resources present throughout the urban basin of Toronto (GXN, 2026). The methodological, technical, and operational protocol of the project is strictly articulated into 6 distinct phases:

01 Urban Mining and Strategic Sourcing

The first phase focused on identifying and collecting decommissioned components from various construction sites across the city, including residential renovations, demolished buildings, and public infrastructure works.

· Territorial Inventory and Cataloging:
The design process began by mapping available waste materials in Toronto to create a true palette of circular resources. The designers studied the components not only based on their physical conditions and structural capacities, but also regarding their origin and cultural/narrative history.

· Selection of Local Resources:
The recovered material palette includes early 20th-century historic bricks (sourced from a demolished church in Toronto’s east end and townhouses in the Annex neighborhood, originally produced in the Don Valley), concrete masonry units (CMUs) left over from new construction sites, lumber from residential renovation works, manhole covers recovered from public utility works, concrete cores, and Muskoka chairs, icons of Canadian outdoor life.

02 Processing, cleaning, and component validation

Once the collection of raw materials extracted from the urban fabric was complete, the second phase required targeted technical interventions of cleaning, remediation, and quality control to certify their suitability for use within a new public space open to the community.

· Selective Cleaning and Preservation of Integrity:
Historic clay bricks and stone elements were entrusted to qualified technical partners (such as Arcana Materials) to be carefully cleaned, brushed, and freed from historic cement mortar residues or external pollutants, while protecting the patina of time and the structural strength of the block.

· Verification of Technical Performance:
Each lot of recovered material underwent qualitative evaluations aimed at checking its mechanical resistance, stability, and safety in use. This testing process changes heterogeneous construction waste into reliable, certified technical components capable of replacing virgin raw materials and drastically reducing the carbon emissions associated with traditional procurement.

03 Codification of circular logic

The third phase translates the recovered waste material palette into a coherent, modular, flexible construction system intrinsically oriented toward dry assembly, overcoming the permanent assembly logics typical of ordinary construction.

· Conception of Modular and Combinational Elements:
The design team studied ways to combine apparently modest and dissimilar materials into complex functional sets, destined to compose multifunctional urban furnishings, seating, protective elements for public space, and structural support bases.

· Elimination of Chemical and Permanent Binders:
To avoid the irreversible destruction of components at the end of their use, the project completely banned the use of cement mortars, chemical adhesives, or structural glues. Instead, it opted for a constructive language based on interlocking geometries, superposition, and mechanical tensioning, which guarantee clean dismantling and total closed-chain reusability.

04 Designing for variability

Given the inherently uncertain and mutable nature of reclaimed materials (characterized by variable dimensional tolerances, non-homogeneous physical conditions, and availability subject to sudden changes), the fourth phase required a mindset shift founded on geometric flexibility rather than standard millimetric precision.

· Preventive Prototyping and Full-Scale Testing:
Before proceeding with final on-site installation, physical full-scale prototypes were developed and tested off-site. This experimental phase allowed for the verification of the actual behavior of the devised construction details in the field, identifying in advance key points where the system was required to adapt to material irregularities.

· Adaptable and Resilient Solutions:
The designers showed how the most durable solutions are also the most flexible: for instance, recovered wooden beams were designed to be used as full-height single elements where material length permitted, or spliced by assembling shorter pieces where availability varied, ensuring identical structural and aesthetic performance of both cases.

05 Constructive approach “Stacked and Strapped”

The fifth phase represents the technological and constructive core of the installation, defining the assembly technique adopted to safely and reversibly assemble the entire Waterfront Neighborhood Space without resorting to welding or cast-in-place works.

· Dry Technique via Gravity and Physical Stability:
Individual brick and concrete block components are carefully dry-stacked following accurate geometric patterns to serve as column bases and supports for benches, while recovered wood columns and beams are connected via specially designed bolted joints to facilitate non-destructive disassembly.

· The Mechanical Strapping System:
The distinctive structural innovation consists in the adoption of the “stacked and strapped” approach: the use of high-strength fastening straps tensioned with accuracy makes it possible to bind and stabilize the set of superimposed elements solidly and securely, entirely eliminating the need for chemical joints and allowing the work to be dismantled with extreme rapidity.

06 Design for Disassembly

The sixth and final phase institutionalizes the principle of the intervention’s integral reversibility, coherently responding both to the momentary nature of the public space and to the long-term goals of urban ecological transition.

· Guarantee of Active and Extended Circularity:
Keeping the installation’s temporary destination in mind, the entire project was conceived so that every single component can be dismantled, cleaned, and reused without suffering any physical, structural, or chemical damage at the end of its public exhibition.

· Material as a Permanent Resource:
Thanks to the total absence of contamination from glued composite materials, the components of the Waterfront Neighbourhood Space can be easily reintroduced into new building or urban cycles, concretely demonstrating that material waste can evolve into a permanent, regenerative architectural resource ready for a second, third, or nth operational life.

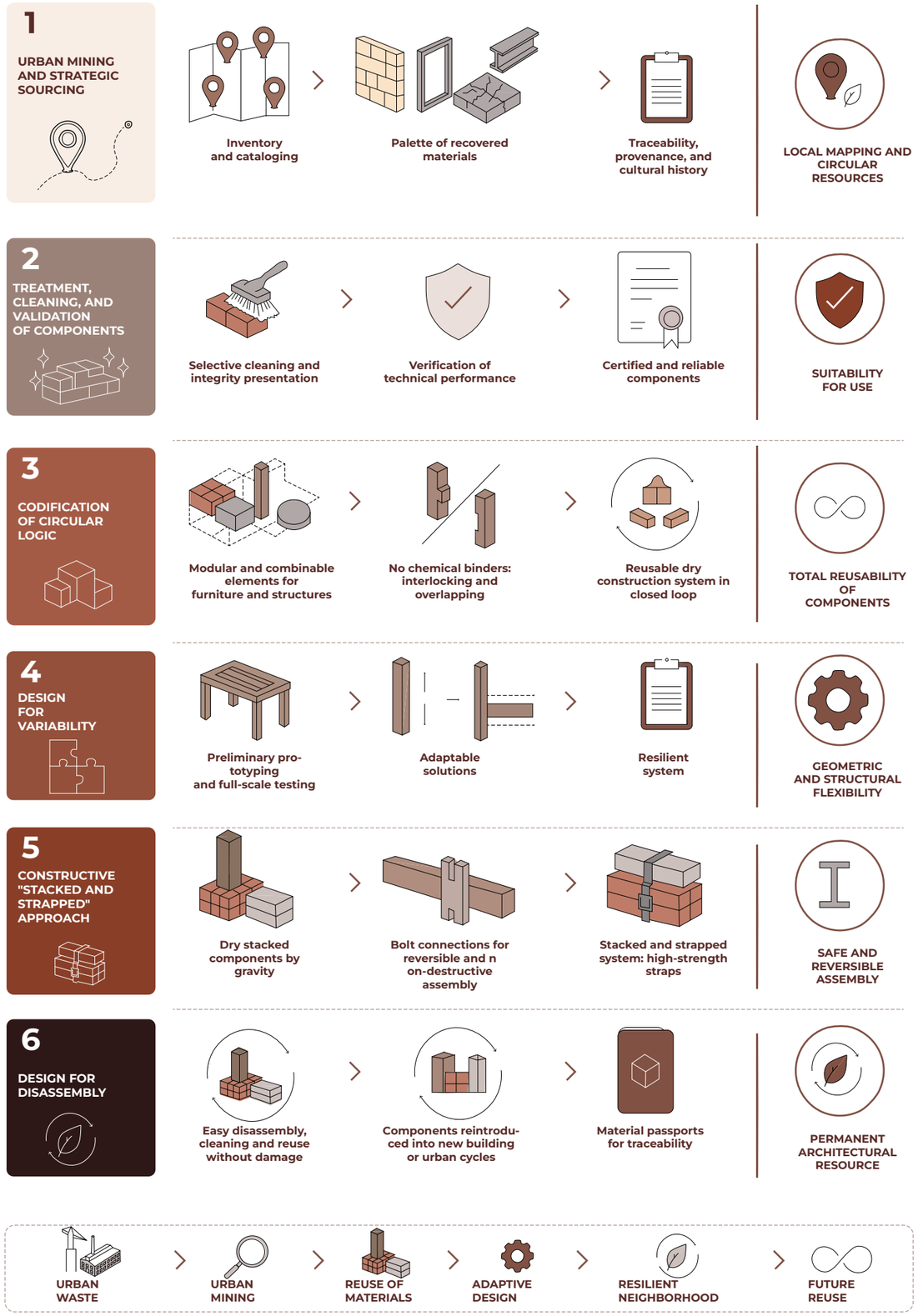


Fig. 69_The Waterfront Neighbourhood Space Protocol. Source: *personal processing*

Quantitative analysis

In an urban ecological transition and local resource valorization context, success is measured not by built floor area but by the ability to divert precious matter from landfill streams, transforming construction waste into a high-performance architectural vocabulary (GXN, 2026).

Urban Mining

The maintenance and direct utilization of 100% of waste components salvaged from city demolitions and renovations guaranteed the ecological and financial sustainability of the entire operation.

· Technical and Procurement Data:
The pavilion and public furniture rest on a rigorously local palette of resources, including early 20th-century historic bricks (sourced from a demolished church in Toronto's east end and townhouses in the Annex neighborhood), leftover concrete masonry units (CMUs) from recent construction sites, lumber from residential renovations, and street manhole covers.

· Costs and Avoided Waste:
By avoiding landfill disposal of tons of decommissioned building material, the economic burden linked to local disposal taxes was drastically reduced, and the ecological effect of long-distance transport was eliminated.

· Material Efficiency:
Thanks to careful forensic cataloging, it was demonstrated that the recovered components possessed mechanical and physical characteristics fully suited to the new public destination, proving that waste material does not necessarily require an energy-intensive downcycling process, but can be directly reintegrated into the construction cycle.

The Construction System and Dry Logic

The absence of chemical binders and the adoption of the dry construction system represent the technological core of the intervention.

· The Function of Strapping:
The assembly system based on tensioning straps and superposition (stacked and strapped) made it possible to stabilize heavy elements such as bricks and blocks without using cement mortars or glues. This eliminated chemical irreversibility processes, supporting rapid and clean assembly without heavy machinery on-site, a key element for a public and community area.

· The Kit as a Logistical Hub:
The recovered and assembled components were not exclusively preserved, but refunctionalized as urban furnishings, seating, and structural bases.

The Embodied Carbon Balance

In advanced North American urban projects, reducing embodied carbon is now a fundamental metric for measuring climate resilience along with compliance with city decarbonization policies.

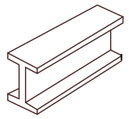
· Alignment with Global Climate Targets:
Without the scientific validation of intensive waste material reuse, the project would not have met the strict standards required by international initiatives such as those of C40 Cities and Waterfront Toronto.

· Carbon Intensity and Circularity:
The project achieves an extreme profile of sustainability, demonstrating how the use of second-hand resources nearly eliminates emissions linked to the production of new building elements, protecting the intervention from any form of ecological obsolescence.

· Impact Equivalence:
To give a concrete dimension, the reuse of thousands of historic bricks, concrete blocks, and wooden beams equates to avoiding the production of new virgin industrial matter and bypassing hundreds of kilometers of road transport within the metropolitan logistics network of Toronto.

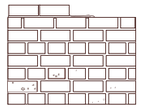
Quantitative estimate

Starting from the qualitative information and spatial data documented in official reports and on the digital portals of design firms, this research uses a quantitative estimate. This analysis processes the available data to assess the actual extent of recovered and upcycled materials, addressing the fragmentation of public metrics through a calculation model based on reference case studies.



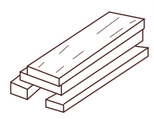
120 TONS STEEL

BEFORE: industrial metal structures
AFTER: Support structure and parapets



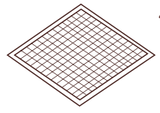
480 m² STONE

BEFORE: Former retaining walls
AFTER: Low walls, steps, seating



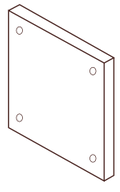
650 m WOOD

BEFORE: Piers and wooden structures
AFTER: Seats and street furniture



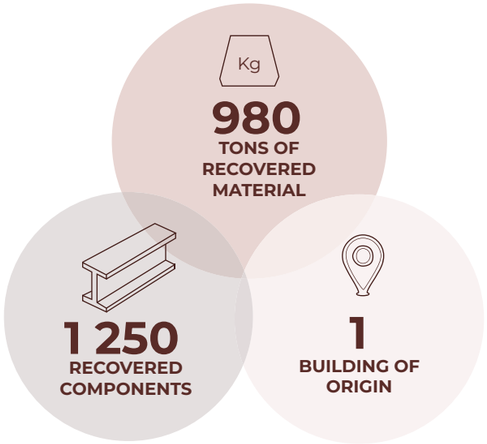
320 m ALUMINUM

BEFORE: Former railings and furnishings
AFTER: Parapets, furnishings, and lighting



2 100 m² CONCRETE

BEFORE: Former platforms and pavements
AFTER: Draining pavements and paths



* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 70_Quantitative analysis of the Waterfront Neighborhood Space. Source: *personal processing*

Economic analysis

Although the initial costs related to logistics and manual cataloging require special attention, the overall financial balance highlights a highly efficient economic model capable of slashing procurement costs while generating exceptionally high use and relational value for the community (GXN, 2026).

Avoided Costs

Economic savings do not stem solely from avoiding expenditures on new materials, but also from eliminating logistical liabilities and landfill disposal costs.

· Raw Materials and Volatility Protection:
Sourcing historic bricks, concrete blocks, and reclaimed timber directly from city construction sites eliminates the purchase costs of virgin materials.

· Urban Logistics and Transport Charges:
Collecting waste materials already present within the Toronto metropolitan area and reusing them locally drastically reduces the number of heavy vehicle trips required to transport new materials.

· Landfill Disposal Taxes:
Preventing tons of bricks, wood, and concrete from ending up in municipal disposal sites zeroes out heavy tipping fees. This direct savings amply offsets the initial operating costs required for selecting, cleaning, and certifying the recovered components.

Additional Costs (Extra-costs)

The economic budget shifts from simply supplying raw materials to investing in "knowledge," process engineering, and specialized artisanal labor.

· Cataloging and Recovery Engineering:
The time and resources dedicated to the preventative mapping of decommissioned materials, the creation of the resource catalog, and the study of reversible construction details require a higher design commitment than a conventional project. This cost stands as a strategic de-risking investment.

· Specialized Labor for Cleaning:
Cleaning historic bricks from mortar residues, selecting lumber, and preparing heterogeneous components calls for careful manual and technical interventions.

· Prototyping and Off-Site Adaptability:
Developing and testing full-scale prototypes to assess the "stacked and strapped" construction system requires dedicated economic resources in the initial phase, which are nonetheless indispensable for preventing on-field errors and guaranteeing the absolute stability and reversibility of the public work.

Asset Value and Social Impact

Why does a partnership composed of public entities, municipalities, and international organizations like Waterfront Toronto and C40 Cities choose this circular approach?

The answer lies in the overall value generated for the community and the territory:

· Speed of Realization and Operational Agility:
Thanks to the use of locally available components and a rapid dry-assembly logic, the public space was completed and made usable in record time, immediately presenting tangible benefits to the local community's daily life.

· Resilience and Cultural Value of the Material:
An installation built with historic Don Valley bricks and reclaimed timber is not simply a temporary infrastructure, but a cultural manifesto telling Toronto's material history. This imparts an inestimable identity and civic value to the intervention that cannot be replicated with anonymous industrial products.

· Conformity to ESG Criteria and Subsidized Financing:
The rigorous adoption of circular economy principles, waste elimination, and carbon footprint reduction fully mirrors ESG (Environmental, Social, and Governance) parameters, facilitating access to funds dedicated to ecological transition and strengthening the city's leadership in urban sustainability policies.

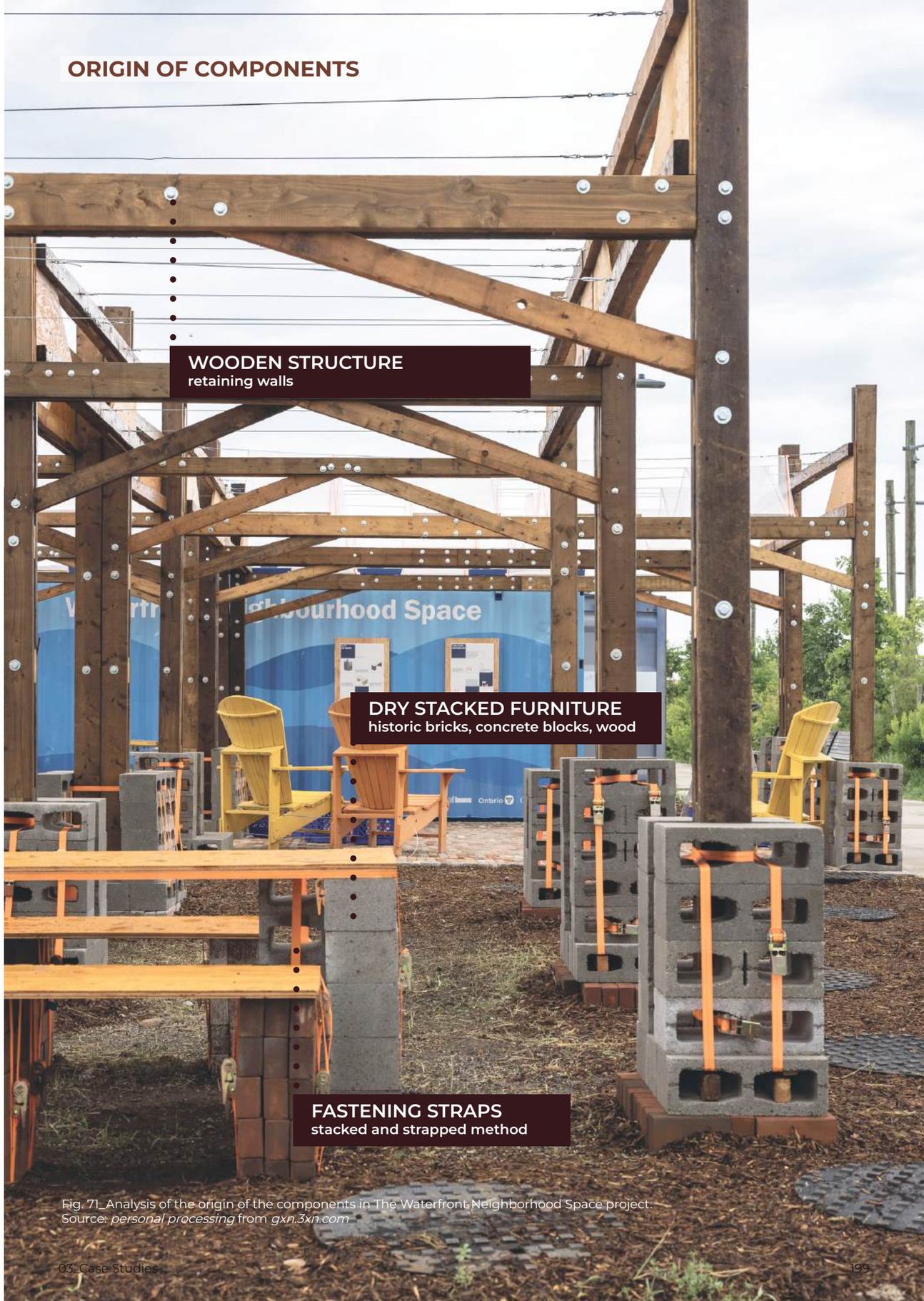


Fig. 71_Analysis of the origin of the components in The Waterfront Neighborhood Space project.
Source: *personal processing* from *gxn.3xn.com*

Problems and Successes: Lesson Learned

The Primary Problem: Material Uncertainty and Regulatory Variability

The primary technical, logistical, and bureaucratic obstacle encountered during the development of the Waterfront Neighbourhood Space was managing the intrinsic uncertainty associated with using reclaimed materials from various demolition contexts, while guaranteeing conformity with stringent Canadian regulations for open public spaces.

· Dimensional Tolerances and Inhomogeneity:
Unlike standardized industrial components, historic Don Valley bricks and waste timber exhibited dimensional variations, irregular tolerances, and uneven wear levels, making a rigidly geometric design impossible.

· Flexibility- and Prototyping-Based Approach:
Instead of imposing rigid prescriptive specifications that would have discarded most of the material, the team opted for an approach based on tolerance and adaptability:

· Full-Scale Testing: Through early off-site prototyping, designers verified the actual behavior of construction details under real loads, perfecting contact nodes.

· Elastic Geometric Solutions: The design of wooden joints and brick bases was conceived to tolerate dimensional deviations, proving that the most resilient construction details are also those most open to the variability of waste material.

Community and Civic Success: The Metamorphosis of Waste

The most significant success of the Waterfront Neighbourhood Space consists in demonstrating that radical upcycling is able to elevate the quality and use value of a temporary public space, transforming construction waste into a catalyst for sociality and urban identity.

· Identity and Relational Value:
The challenge was to transform poor and waste materials (1911 bricks, manhole covers, concrete blocks) into a welcoming infrastructure for events, play, and daily moments. The result rewarded the combination of design and historical narration, offering the community a space full of cultural meaning that new commercial constructions or standardized materials could never express.

· Consensus and Participation:
The project received overwhelming appreciation from institutional partners (Waterfront Toronto, C40 Cities, and the City of Toronto), proving the effectiveness of a model based on circular economy applied to civic space.

Towards Reversible Architecture

The issues related to manipulating heterogeneous elements and the need to guarantee the total removability of the installation taught fundamental lessons about reversibility as well as the material lifecycle:

· Mechanical Connections Free of Glues:
The total absence of chemical mortars and the adoption of the “stacked and strapped” (superimposed and strapped) system resolved the critical issue of end-of-life disassembly, making sure that no component suffers permanent alterations or contamination.

· Design for Disassembly (DfD):
The entire pavilion is not conceived as a static artifact, but as a structure intrinsically designed to be dismantled, reconfigured, or reused elsewhere once its temporary function ends.

· The Urban Paradigm Shift:
The installation proves that construction waste does not necessarily have to undergo energy-intensive downcycling processes, but can be directly redeployed in closed loops, converting cities into open and regenerative material banks.

The overall success proves that circularity pushed to the extreme is not a formal limit, but a generator of cultural, ecological, and community value.





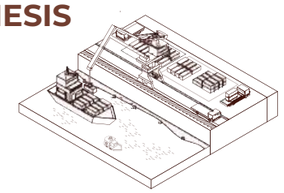




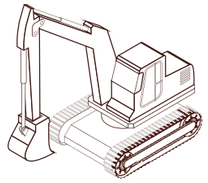


Fig. 72_Photographs of the construction site of The Waterfront Neighborhood Space project. Source: *gxn.3xn.com. xn*

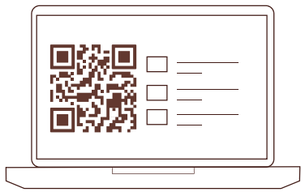
SYNTHESIS



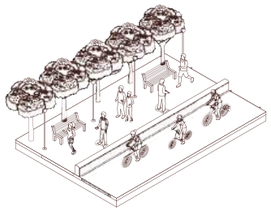
PORT AREA DISUSED



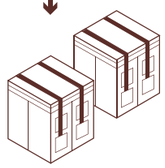
URBAN MINING



MATERIAL PASSPORT



PUBLIC SPACE



WATERFONT NEIGHBOURHOOD SPACE

-720 t *
CO_2 eq. avoided

-40 % *
total cost

-88 % *
waste produced

* Value estimated through AI support (Gemini) through comparative analysis between the upcycled process and traditional demolition

Fig. 73_Summary diagram of the Waterfront Neighborhood Space project. Source: *personal processing*



Fig. 74_The Waterfront Neighbourhood Space. Source: *gxn.3xn.com*

CHAPTER FOUR

04

Lesson Learned: critical analysis and limitations of current practice

4.1. The uncertainty of anonymous matter

The main obstacle intrinsic to upcycling within the urban mine lies in the technical and legal identity crisis that affects reclaimed matter. The moment it is removed from its original setting, each component loses its industrial pedigree and transforms into anonymous matter, that is, devoid of historical traceability, origin certifications, and updated performance guarantees. In a sector dominated by the culture of structural safety, standardization, and rigorous risk mitigation, this anonymity itself erects an insurmountable barrier, divided between physical limits and regulatory limitations that are closely interconnected.

From a technical perspective, significant uncertainty remains regarding the mechanical functioning, fatigue, and future durability of elements that have already lived an entire lifecycle within a building organism. The absence of non-destructive diagnostic methodologies that are economically and operationally sustainable directly on-site prevents the verification of the residual properties of the matter with scientific exactness. This informational asymmetry inevitably drives designers, construction managers, and structural inspectors (upon whom rests the entire civil and criminal liability for the stability of the work) to reject the circular resource and prefer the industrial virgin product, whose reliability is guaranteed upfront by standardized technical datasheets.

From a legal and regulatory standpoint, the phenomenon of regulatory lag manifests instead, namely the dramatic disconnection between ecological transition policies and the actual evolution of building regulations. The prevailing regulatory systems, starting from the European Construction Products Regulation (CPR 305/2011) up to the Technical Construction Standards (NTC) at the national scale, are conceived on the presumption that every material originates from a controlled, repeatable, and CE-marked factory process. The reclaimed component thus finds itself trapped in an insurmountable regulatory paradox: environmental legislation classifies it as waste (identified by strict EWC codes), making its management complex and bureaucratized, whereas building legislation prohibits its installation in the absence of updated certificates that no original manufacturer is willing to provide anymore, effectively confining upcycling within a gray zone of grave legal uncertainty.



Fig. 75_Villa Welpeloo - Superuse Studios, Netherlands 2009. Source: *superuse-studios.com*

Performance uncertainty

The main challenge in implementing an operational upcycling protocol lies in the technical, performance-based, and legal validation of components extracted from existing building organisms, which lack exhaustive historical documentation, original technical datasheets, or certified origin traceability. This condition of informational opacity transforms the reclaimed material into what can be defined as “anonymous matter”: a physical entity endowed with latent potential, yet deprived of its technical and legal identity and the guarantee of needed reliability for reinsertion into a new construction cycle (Raga et al., 2021).

Unlike virgin materials, which enter the building market escorted by Declarations of Performance (DoP), CE markings, and standardized certifications provided by the manufacturer (guaranteeing the statistical homogeneity of the batch and strict compliance with set resistance thresholds), the upcycled component intrinsically carries the marks and microstructural alterations resulting from its previous lifecycle (Crowley et al., 2019). In critical structural elements, such as steel profiles, prefabricated reinforced concrete macro-components, or structural timber species, uncertainty does not solely concern macroscopic geometry or surface conservation status, but affects the very nature of the matter.

Hidden degradative phenomena that are undetectable through simple visual inspection represent the main threat to project safety.
Consider micro-fractures from cumulative fatigue in metal structures undergoing to recurring loads, localized yieldings resulting from past accidental overloads, or complicated phenomena of interstitial corrosion that may have compromised the load-bearing section in critical, uninspectable points.

Securing **structural safety** and indoor environmental health thus becomes an operation that exceeds engineering calculation: it is necessary to transition from reassuring passive trust in the industrial technical datasheet to the necessity of advanced, dynamic, and punctual instrumental diagnostics. Each recovered piece assumes the dignity of a unique prototype to be validated individually. Every beam, every panel, and every joint must undergo a sort of technical anamnesis that certifies its physical and chemical suitability for the new use.

The integration of **non-destructive testing (NDT)** thus becomes an essential and early phase of the design workflow, subverting traditional project chronology. Techniques such as ultrasonic and magnetic particle testing to verify metal homogeneity, sclerometry and pachometric testing for concrete, or infrared thermography to identify hidden detachments or thermal bridges, are no longer post-construction diagnostic tools, but search engines for the matter itself.

Alongside mechanical stability, the issue of **biochemical healthiness** strongly emerges. Anonymous matter can conceal pitfalls linked to old past regulation standards: consider the possible presence of lead in protective paints, asbestos in cementitious or insulating matrices, or formaldehyde and volatile organic compounds (VOCs) in vintage resin binders. The use of spectrometric analyses and in situ chemical tests becomes the sole instrument capable of providing the chemical biography necessary to reintroduce the component into the legal production cycle without risks to public health.

This paradigm shift dictates that design no longer occurs on abstract bases, but on certified diagnostic evidence. The vulnerability of anonymous matter is overcome through a **process of retroactive performance re-certification**, conducted within specialized territorial Hubs (Hradil et al., 2014).



Fig. 76_Industrial waste conversion by Playground Wikado - Superuse Studios, Rotterdam, 2008. Source: *superuse-studios.com*

The failure of Design for Deconstruction (DfD)

Within the constellation of performance and diagnostic uncertainties weighing upon anonymous matter lies an intrinsic and ancestral technological limit of the existing built heritage, which can be defined as the fundamental failure of Design for Deconstruction (DfD) (Durmisevic, 2019).

If today the most advanced architectural research, European decarbonization directives, and latest-generation regulatory protocols strongly promote reversible design for the future, the operational reality of construction sites imposes a far more complex truth: upcycling and urban mining activities must be practiced here and now on an immense real estate stock built predominantly between the post-WWII period and the early 2000s. The structural, systemic, and seemingly insurmountable problem of this massive volumetric mass lies in the fact that it was conceived, engineered, and assembled while deliberately ignoring the temporal dimension of end-of-life, responding to construction logics based on total and irreversible solidarity among components (Thormark, 2006).

Striking examples of this structural and constructive irreversibility are encountered daily in construction site case studies:

- External Thermal Insulation Composite Systems (ETICS):
Polystyrene or rock wool panels glued with high-tenacity cementitious adhesives directly onto brick substrates and subsequently skim-coated with fiberglass meshes and plastic plasters.

- Improper False Ceilings and Partitions:
Plasterboard panels bonded via complex acrylic adhesive systems directly onto metal frameworks or underlying masonry, rather than fixed using removable mechanical screws.

- Flooring and Radiant Heating Systems:
Cementitious or self-leveling screeds poured directly over studded insulation panels and cross-linked polyethylene pipes, integrating hydraulic, plastic, cementitious, and ceramic components into a single, indivisible block.

In a technological scenario dominated by such indissoluble multi-material couplings, the concept of selective deconstruction clashes with an impassable barrier, proving to be a design utopia or, at worst, a theoretical mystification (Addis, 2006). Separating layers of chemically and physically cohesive materials without destroying or mutually contaminating them is operationally impossible. Consequently, the act of disassembly inevitably transforms into a traumatic, violent, and intrinsically destructive process.

This demonstrates that the performance uncertainty plaguing materials extracted from the urban mine is not simply the result of biological wear over time, freeze-thaw cycles, or the natural aging of polymer and cementitious matrices. It is, to a large extent, the direct consequence of the extreme, dynamic, and unforeseen mechanical stresses to which components are subjected during forced detachment. To recover any construction element, the site operator is forced to use cutting, chipping, and percussion actions, breaking connections and joints that were originally designed to be eternal, rigid, and monolithic.

The invisible micro-fractures induced in resistant sections by the high-frequency vibrations of demolition hammers, the abrasions and deep tears caused by the mechanical removal of cementitious adhesives and resins, and the permanent plastic deformations suffered by metal profiles in the attempt to unbind them from wet pours fundamentally and irreversibly undermine the structural reliability, safety, and aesthetic quality of the recovered resource.

The historical failure of Design for Deconstruction at the outset thus translates into a severe performance sentence for secondary matter: the deconstruction site, unable to operate surgically on irreversible construction nodes, is forced to act destructively.

The Regulatory Lag

Contemporary architecture finds itself trapped in a paradoxical limbo, where scientific awareness clashes with the viscosity of bureaucratic, legislative, and industrial apparatuses (Hegger et al., 2006). On one hand, climate reports and thermodynamic evidence scream the immediacy of radical and immediate decarbonization, pointing to the built environment as our largest reserve of saved carbon (Thormark, 2006); on the other hand, the entire framework overseeing the construction sector seems to move according to an out-of-sync, almost geological temporality, remaining anchored to the extractive logics of the past century. This profound and systematic system-level asynchrony represents the true reef against which the ambitions of an urban regeneration that aspires to define itself as authentically ecological break on a daily basis (Addis, 2006).

While the theory of upcycling and structural recovery has already widely demonstrated its own scientific validity, revealing how the maintenance of the building skeleton is the only true strategy to slash emission impacts in the short term (Akbarnezhad et al., 2014), a brutal question spontaneously arises: *why does site practice continue to favor the reassuring and violent linearity of demolition?*

The problem is no longer (and perhaps never was) purely technological. We possess the engineering capabilities to map the residual value of materials, to reinforce dated structures, and to integrate avant-garde plant systems into pre-existing envelopes (Gorgolewski, 2018). Yet, we find ourselves immersed in a regulatory setting that, while citing sustainability and the circular economy in every ceremonial preamble, was created in an era of energy abundance and unlimited land consumption (Kibert, 2013).

How is it possible that perfectly intact structural components, which have demonstrated their toughness for decades, are instantly downgraded to scrap or waste the exact moment they are dismantled or refunctionalized?

Why must the legal liability of the designer transform into an inextricable network of insurance risks when attempting to certify the performance of a recovered material, whereas the path of demolition and ex-novo reconstruction is paved with incentives, procedural certainties, and streamlined protocols?

This difference, which we might define as an **evolutionary lag of institutions relative to the speed of the biosphere**, creates an unbridgeable fracture between what climate physics imposes upon us to do and what civil law, technical standards, or waste regulations permit us to achieve smoothly. It is a conflict that directly invests the culture of risk and profit: tabula rasa has become the comfort zone of the global real estate market not because it is ecologically superior, but because it is procedurally more predictable (Silva et al., 2017).

Exploring these barriers therefore means overcoming the contradictions of a system that travels at dramatically different speeds. While several cutting-edge international contexts have begun to successfully experiment with material passports and introduce taxation based not only on volume but on total carbon footprint (Raga et al., 2021), a large portion of the regulatory fabric is anchored to a stiffness that suffocates regenerative ingenuity.

What are the occult forces preventing the birth of a true industrial supply chain of selective dismantling? Is it truly only a matter of direct economic costs, or are we facing a serious cultural opposition that views the existing building as merely an obstacle to maximizing land value?

For decades, European legislation interpreted architectural sustainability almost exclusively through the lens of energy consumption during the use phase, promoting standards such as the NZEB (Nearly Zero Energy Building). This approach, although necessary to cut utility bills and operational emissions, generated a dangerous perceptual and legislative distortion: it tended to make people believe that a new building was inherently greener than an existing one, systematically ignoring the immense emission debt generated for its construction. Recently, the framework has evolved with the introduction of the Level(s) system and

the request to monitor Whole Life Carbon, signaling Brussels' willingness to finally account for the embodied carbon footprint embedded within matter. However, the transition from political recommendation to technical sanction or performance obligation is hindered by a systemic resistance from individual governments, concerned about the direct economic impact on a construction supply chain that has always prospered on building replacement rather than structural regeneration.

The core of Regulatory Lag lies precisely in the national transposition process, where directives often lose their reformative momentum to become mere bureaucratic fulfillments. Each member state possesses a stratification of building codes, technical safety standards, and waste regulations that often enter into direct conflict with the ambitions of the circular economy and upcycling. In many continental contexts, legislation remains historically centered on technological replacement (new insulation, new systems, new materials) rather than the preservation of original material integrity.

Why do laws not run as fast as the emergency?

One of the fundamental reasons lies in the **complexity of technical harmonization**: administrative and technical law ontologically prioritizes the certainty of certified industrial data over the apparent uncertainty of recovery.

The current regulatory system was built on a prescriptive logic: safety is guaranteed by the use of a new material, with a CE marking, a predefined technical datasheet, and a manufacturer's warranty. Conversely, a regulation that truly wishes to incentivize upcycling would require a paradigm change toward a performance logic: it is no longer a matter of prescribing the purchase of a new "green" component, but of scientifically demonstrating that an existing structure can still fulfill its static function and safety requirements, perhaps through less invasive reinforcement techniques than total demolition (Hradil et al., 2014).

This transition is extremely slow because it disrupts decades of consolidated practices, throwing into crisis not only site processes, but the entire system of legal liabilities and insurances. Insurance policies and structural inspectors see in the new the only procedural comfort zone, since liability is easily traceable along the production chain. In reuse, however, liability heavily falls upon the designer and the inspector, who find themselves having to guarantee matter whose original production they did not sign. Without a regulatory shield or simplified approval procedures, the professional is driven to advise demolition, destroying that carbon capital they nonetheless recognize as precious.

In this scenario, the perspective of carbon capital shifts the focus of architectural preservation toward unprecedented and politically disruptive horizons. Preservation can no longer concern only what is historical or monumental according to the canons of traditional aesthetics or decorative value; it must obligatorily extend to what is energetically dense. Even the anonymous suburban warehouse, the industrial silo, or the reinforced concrete office building acquire **ethical and climatic dignity** precisely as massive containers of embodied carbon. Upcycling architecture thus becomes the custodian of an energetic memory that current law struggles to recognize, transforming the technical necessity of recovery into an act of high-profile planetary responsibility. Material savings must begin to coincide, legally and fiscally as well, with respect for the emission effort that built our modern urban civilization: demolishing a 1960 building is not simply a construction act; it is the brutal cancellation of an energy investment that the planet has already paid dearly for.

Furthermore, Regulatory Lag is caused by the **lack of a shared metric for evaluating past emission efforts**. While the market value of a building fluctuates based on the real estate exchange, its carbon value is an objective physical datum that nevertheless finds no place in municipal budgets. If we integrated the concept of carbon capital into the preliminary phases of every master plan, demolition would be perceived not as an opportunity for regeneration, but as a net loss of public heritage. Every ton of demolished concrete should appear as a climatic fine subtracted from the future, making upcycling not only an ethical choice, but the only economically rational move in a resource-constrained world.

However, the upgrading of bureaucratic competencies necessary to absorb this change is still far from being a reality in individual member states. The municipal technical official or regional inspector today finds themselves devoid of regulatory tools that allow them to validate reuse without exposing themselves to personal risks or sanctions for accounting damage. As long as the calculation of Embodied Carbon is not compulsorily integrated into the preliminary phases of every urban intervention (equating it in binding importance to building density indices, daylighting ratios, or extremely strict anti-seismic requirements), we will continue to produce hyper-technological ecological boxes. The latter, in the attempt to save the planet through functional effectiveness promised for the next thirty years, destroy its foundations in the present through the systematic demolition and parsimonious consumption of new untouched resources.

The challenge of Regulatory Lag is therefore, ultimately, a challenge of civilization and language: it is about **realigning the time of bureaucracy with the time of the biosphere**, stopping the consideration of demolition as a painless tabula rasa or an opportunity for renewal, and beginning to treat it as the tragic dissipation of a carbon capital that we can no longer afford to waste. Only by integrating this sensitivity into technical codes can we honor the energy debt contracted with the past, avoiding the construction of buildings that are "green" only on paper but carry with them the invisible footprint of climatic destruction already occurred on-site.

THE LEGAL STATUS OF MATTER

Overcoming the current stagnation of upcycling inevitably passes through the reform of national legislative systems which, while adopting European directives on climate neutrality, remain anchored to an ultra-protective logic that a priori assimilates waste to a danger.

The structure of contemporary environmental law, historically built to combat illegal disposal, illicit waste trafficking, and soil pollution, adopts a predominantly sanctioning, defensive, and remedial approach. This setup generates a systemic short-circuit when attempting to apply the advanced principles of the circular economy and Regenerative Design to construction: the state bureaucratic apparatus, in fact, is not structured to recognize the qualitative nature of the residue, ultimately treating toxic industrial sludge and an architectural structural or finishing element removed intact from an existing building organism with the exact same regulatory severity.

The paradox of the End-of-Waste regime is that a building component extracted intact from selective deconstruction is legally cataloged as waste, forcing the supply chain through extraordinarily long and uncertain bureaucratic paths that push toward landfill disposal or downcycling (Pacheco-Torgal et al., 2013). According to the current regulatory framework, any substance or object of which the holder discards, intends to discard, or is obliged to discard is legally configured as waste. The act of deconstruction and surgical dismantling, rather than being codified as the first phase of a new value chain and the beginning of a second lifecycle for the component, automatically and rigidly triggers binding classification employing EWC (European Waste Catalog) codes. To reacquire the civil status of a product and be legitimately reintroduced onto the market and into the project flow, the removed element must pass long, costly, and asphyxiating examination procedures attesting compliance with rigid technical, chemical, and environmental criteria. The lack of specific, flexible End-of-Waste decrees declined for the various macro-categories of reusable building components forces designers, construction managers, and exe-

cuting firms to operate under a regime of constant legal uncertainty and penal vulnerability, exposed to prosecution for illicit management or unauthorized waste trafficking. Consequently, supply chain actors tend to bypass high-value-added recovery, preferring the downgrading of matter via indiscriminate crushing for road sub-bases or, in the worst cases, definitive landfill disposal, thus dissipating the embedded embodied energy (Embodied Carbon) consolidated within the artifact.

The transition requires the introduction of the **Legal Status of the "Component Awaiting Reuse,"** a flexible third administrative category allowing cataloged materials to transit directly between sites while maintaining the qualification of a building resource (Durmisevic, 2019). This new legal institution should definitively dismantle the binary "product-waste" dichotomy, recognizing a condition of protected temporariness for all those components extracted via engineered processes of selective deconstruction. The attribution of this formal qualification presupposes the mandatory execution of a preliminary audit on the donor building, capable of certifying the traceability, healthiness, and potential quality of components even before their physical removal from the built stock. Through this ex-ante digitization, structural elements would uninterruptedly maintain their economic value, commercial legitimacy, and constructional dignity, being stochastically stored, handled, and freely marketed within an integrated network of urban and territorial sites, without ever activating the complex, penalizing, and humiliating bureaucratic procedures typical of industrial waste treatment and disposal centers.

This process of controlled deregulation must be supported by **asymmetric ecological taxation**, such as a Carbon Tax on virgin raw materials: by taxing the extraction of the new and simultaneously defiscalizing the labor cost linked to the workforce for surgical deconstruction, the construction market would be spontaneously and conveniently oriented toward recovery practices. Currently, the linear economic model is artificially and heavily incentivized by the low market cost of fossil, polymeric, or extractive raw materials, whose final price does not internalize the devastating global ecological damages linked to extraction, refining, chemical synthesis, and long-range transport. Introducing taxation proportional to the carbon footprint embodied in virgin materials (such as primary cementitious concrete, extruded aluminum from extractive ore, or blast furnace steel) would drive a natural, rapid, and inevitable rise in procurement costs for major real estate developers. At the same time, the resources deriving from such ecological taxation should not flow into current public spending, but be systematically and entirely destined to the total tax exemption of social contributions for specialized craftsmanship engaged in controlled dismantling and conditioning operations of recovered matter. Since selective deconstruction is an intrinsically labor-intensive process (demanding extended time, execution precision, and high intensity of specialized labor) compared to massive and blind destruction operated via mechanized demolition with shears or explosives, shifting the tax burden from the labor force to virgin matter would re-establish competitive equity on an economic plane. The upcycling project would thus cease to configure itself as an ethical but financially penalizing option, transforming into the most financially strategic, convenient, and high-performance choice for the entire public and private clientele, accelerating the birth of a structured market for circular matter.





Fig. 77_Overcoming the Regulatory Lag of Liander Westpoort- De Zwarte Hond, Amsterdam, 2023. Source: *archdaily.com - Jaques Tilleman*

The concept of “Waste” and “By-Product”

A deep fault exists between the ecological intent to preserve matter (understood as an irreplaceable repository of primary energy and sequestered carbon) and the bureaucratic practice that regulates its daily management (Hegger et al., 2006). This fault manifests at the exact moment when a structural element ceases to fulfill its original function within a building organism to enter a phase of transition or refunctionalization.

In this key passage, the destiny of an architectural component is not decided by its physical integrity, its residual mechanical performance (often still excellent), or its inestimable potential value in terms of emissions spared for the planet (Thormark, 2006). On the contrary, it is determined by the semantic and regulatory category into which the legislator and regulatory authorities officially confine it.

The distinction between what is considered “waste” to be evacuated and what is recognized as a resource to be reused is not a mere exercise in academic nomenclature or a debate for environmental lawyers; it represents the gravitational center, the breaking point, around which the economic feasibility, the judicial safety of the professional, and the real sustainability of every modern upcycling intervention revolve (Durmisevic, 2019).

If contemporary architecture truly wishes to shoulder the climate crisis, it must initially confront the “civil death” of matter that occurs within demolition sites. Understanding the legislative knot that binds, and often inextricably tangles, the concepts of Waste, By-product, and Cessation of waste status (End-of-Waste) therefore means surgically studying the regulatory devices that effectively sanction the success or failure of the bioscenic accounting of our built heritage today (Kibert, 2013).

Until the law is able to recognize the energy density of existing matter, elevating it to sovereign capital to be protected rather than a volumetric encumbrance to be removed, every effort toward the circular economy will remain trapped in a system that prefers the landfill to the complexity of reuse.

Studying this knot means, ultimately, questioning how the legislator’s word is able to transform a piece of debris into a brick for the future, overcoming an environmental protection regime that, paradoxically, in its obsessive attempt to prevent pollution from illicit waste management, ends up incentivizing global pollution deriving from new industrial production.

It is in this clash between local soil protection and global atmosphere protection that a new ontology of building is decided, where the existing building is no longer viewed as a potential mountain of rubble, but as a golden reserve of embodied carbon that the law has the duty to protect from downgrading into waste.

The stigma of waste

Within the contemporary legislative landscape, the management of decommissioned architectural matter finds itself trapped in a paradox that suppresses any real regeneration potential at birth.

The current regulatory framework, rooted in the Waste Framework Directive and the Italian Environmental Consolidated Act, commits the fundamental error of not evaluating materials for their fundamental qualities, physical integrity, or remaining energy content, instead anchoring them indissolubly to the psychological and subjective concept of discarding. This setup generates a sort of **civil death of matter:** the exact moment a component, whether a profiled steel beam or a glued-laminated timber panel, is removed from its original location with the intention of no longer using it in that specific site, it suffers an instantaneous degradation of its legal status, transforming under the law into a waste indelibly branded with an EWC (European Waste Catalogue) code (Pacheco-Torgal et al., 2013).

Such a transition does not represent a mere formal passage, but activates a regime of surveillance and asphyxiating constraints that transforms the resource into a paralyzing administrative burden. Once classified as waste, the artifact enters a procedural area where every movement is rigidly regulated, requiring storage in authorized and paved areas, often distant from the construction site, and transport escorted by forms whose slightest incorrect compilation can lead to heavy criminal penalties. The most glaring paradox lies in the fact that a structural element that is still perfectly performant, capable of guaranteeing safety for decades and the custodian of an immense embodied carbon value, instantly loses its dignity as an architectural artifact to acquire the ontologically inferior one of scrap, thus acting as an effective systemic deterrent to reuse (Thormark, 2006).

Developing a critical analysis of this stigmatization, it emerges how environmental law involuntarily creates an incentive toward the linear economy and extractivism. For a company or a client, the law today makes it infinitely simpler and safer to purchase virgin materials, which arrive at the construction site accompanied by industrial certifications and CE markings that relieve the designer of any responsibility regarding the origin of the matter. Conversely, attempting upcycling means venturing into a minefield where supply chain actors effectively transform into waste managers exposed to risks of preventive seizure. In this scenario, **legal prudence inevitably wins over environmental protection**, pushing for the demolition of existing structural frames to purchase new ones purely to remain within the bureaucratic comfort zone, condemning the global atmosphere to tons of new CO_2 emissions in the attempt to protect local soil (Raga et al., 2021).

This situation also spurs a dangerous statistical illusion definable as **legalized downcycling**, whereby a building crushed to become a road sub-base is counted as 90% recovered, while from the perspective of bioscenic accounting it is a total failure that wastes the energy and carbon of the original form.

The current law, victim of a morphological blindness, cannot distinguish between formless debris and a structural component endowed with identity, rewarding the thermodynamic destruction of raw matter and punishing the preservation of structural function. As long as the definition of waste stays anchored to the subjective act of discarding without integrating parameters linked to residual carbon capital and verifiable mechanical performance, regulatory lag will continue to stifle upcycling.

The challenge therefore lies in rewriting the legal ontology of matter, identifying the building as a material bank in which components, temporarily deposited, can transit from one artifact to another without losing their legal and energetic dignity, transforming a regulatory dead end into a highway for truly ecological urban regeneration.

The by-product

The concept of the by-product acts as the **legal antithesis of waste**: if waste is the outcome of an act of abandonment or discarding, the by-product is a resource that, while not being the main objective of a process, retains such functional dignity and intrinsic value that it can immediately re-enter the economic cycle (Hegger et al., 2006).

In terms of bioscenic accounting, the by-product is the legal vehicle that allows carbon capital to migrate from one building organism to another without undergoing the civil death of classification as scrap. However, this seemingly salvific definition collides with a regulatory framework (anchored on Article 184-bis of Legislative Decree 152/2006) of such rigidity as to transform what should be a highway for upcycling into a narrow, impervious path strewn with judicial mines (Durmisevic, 2019).

For a material, especially if deriving from structural dismantling or selective demolition operations, to be legally qualified as a by-product, it must satisfy four simultaneous, cumulative, and extremely strict conditions, the proof of which rests entirely on the responsibility of the producer and the designer (Kibert, 2013).

First, the rule demands **certainty of use.** Hypothetical, generic, or time-delayed reuse is not permitted: the material must have a specific intended use, already identified, contracted, and technically defined even before its removal.
In a construction market characterized by fluctuations, design changes during execution, and logistical-related uncertainties, this condition becomes an almost insurmountable obstacle. Keeping a steel column or a wooden portal in storage awaiting a future buyer means, under current law, holding waste pending disposal, exposing the owner to criminal penalties for uncontrolled storage. Certainty must be documentary and immediate, which presupposes a perfect synchrony between the dismantling site and the reconstruction site; a temporal coincidence that rarely occurs in operational practice.

The second requirement concerns the **absence of treatments other than normal industrial practice.** It is here that the essential node becomes exquisitely technical and semantic, opening vast fields of interpretive uncertainty.
What falls under "normal practice"?
If simple surface cleaning of a component can be tolerated, what happens when a beam requires deep sandblasting to remove oxidized paints, or when a metal joint must be straightened or reinforced to meet new structural calculations?
The moment the recovery intervention turns invasive or requires specialized processing, the risk that the control authority downgrades the object to "waste subjected to a recovery operation" is extremely high. This unclearness nips any attempt at advanced upcycling in the bud, limiting reuse only to components that are already virtually perfect and preventing the valorization of those components that, while needing care, harbor tons of embodied carbon.

The third point touches upon a fundamental issue: **origin from a production process.** In this area, the most heated conflict arises between the ethics of sustainability and the practice of the courts (Addis, 2006).
Can the demolition of a building be considered a "production process"?
Traditionally, the bureaucratic vision interprets demolition as a definitive act of destruction, an event generating rubble. If the legislator continues to deny that a deconstruction site is, to all intents and purposes, a reverse factory producing components ready for reuse, the qualification of by-product will remain foreclosed to almost the entire existing built heritage. This short-sighted vision ignores the fact that selective dismantling is an act of environmental value production: extracting an intact floor slab is an industrial operation as complex as producing a new one, with the added advantage of requiring no new extraction of raw materials.

Finally, the material must guarantee **full compliance with all environmental protection and health requirements**, without entailing overall negative impacts (Pacheco-Torgal et al., 2013). Although theoretically impeccable, this point imposes an unsustainable analytical burden on small- and medium-scale recovery. Proving that 1970s concrete or metal treated with vintage primer does not contain infinitesimal traces of substances banned today requires chemical analysis campaigns and destructive testing whose costs often exceed the market value of the component itself. The result is an economic paradox: it is cheaper to buy a new certified piece (even knowing that its production devastated the environment thousands of kilometers away) rather than certify the healthiness of an existing piece (Raga et al., 2021).

Assessing this situation critically, it emerges that the path of the by-product is today a niche, almost heroic option. The risk of incurring criminal penalties for illicit waste management, or worse for operating an illegal landfill, is so concrete that the vast majority of construction managers and firms prefer the linear path of disposal. The bureaucratic peace guaranteed by landfill disposal, with its reassuring forms and well-delineated responsibilities, systematically wins over the ethical challenge of upcycling (Silva et al., 2017).

Ultimately, until legislation recognizes that the conservation of matter is a superior form of environmental protection, and until simplified protocols for the recertification of structural elements are standardized, the by-product will remain a legislative mirage. A paradigm shift is necessary to transform selective dismantling into a protected and incentivized industrial activity, elevating certainty of use from a paralyzing constraint to the strategic objective of urban planning that views the existing not as a liability to be disposed of, but as a golden reserve of resources for the future.

End of Waste: the transformation of value

The institution of End-of-Waste (Cessation of waste status), regulated at the European level by **Article 6 of Directive 2008/98/EC** and transposed into the Italian legal system by **Article 184-ter of Legislative Decree 152/2006**, represents the most delicate legal, technical, and philosophical crossroads of the entire circular economy applied to the construction sector (Kibert, 2013). This is the legal process through which an object or a substance, after being classified as "waste" following demolition or dismantling, undergoes a recovery operation that allows it to reacquire the ontological and commercial status of a "product" (Pacheco-Torgal et al., 2013).

However, although this instrument is theoretically central to achieving the objectives of the Green Deal, the End-of-Waste regime is currently plagued by a Regulatory Lag that limits its effectiveness to a few low-profile applications. The fundamental criticality lies in the very nature of the implementing regulations: specific criteria defining "when" and "how" a material ceases to be waste are rare, fragmented, and characterized by a limited vision of recovery.

In this scenario, the regulatory system seems to admit the recovery of value only on condition of the prior destruction of form. There is a total lack of a harmonized, courageous, and technically advanced regulation that allows a complex structural element to change status through a process of verification, diagnostics, and recertification that preserves its original dimensional and mechanical integrity.

The absence of clear, uniform, and set criteria at the central level transforms the cessation of waste status into a discretionary and slow process. Currently, in the absence of specific national regulations for the reuse of structural elements as such, case-by-case evaluation is entrusted to local authorities (Regions or Provinces). Operating in a climate of legislative uncertainty and fearing heavy liabilities for alleged environmental offenses or omitted controls, the latter tend to adopt an **ultra-conservative and defensive approach**.

The result of the current legislative inertia is a system that systematically rewards downcycling at the expense of high-profile upcycling. If a company decides to reduce a beam into rubble to make road sub-base or fill, the bureaucracy is rapid, tried and tested, and confidence-inspiring. If, on the contrary, the same company attempts to reuse the exact same beam while preserving its load-bearing function, it clashes with administrative silences, disproportionate analysis costs, and legislative voids that make the operation economically disastrous. This disequilibrium transforms reuse into a heroic, isolated practice confined to state-of-the-art experimentation or self-construction, successfully preventing its necessary scalability on an industrial and urban scale.

To overcome this stalemate, shared European technical standards are required, defining non-destructive testing protocols, CE marking methods for reused construction products, and digital traceability databases (such as Material Passports).

Only when a structural element can recover its legal identity as a "product" with the same agility and speed with which it is downgraded to "waste" today are we able to truly speak of an ecological transition in the building sector (Thormark, 2006). Without this profound alignment between law, engineering, and climate protection, End-of-Waste will remain an empty label, a theoretical ambition that in practice forces architecture to continue destroying the past to fuel a present increasingly poor in resources and increasingly dense with irreversible emissions.

The true regulatory challenge consists in legalizing the permanence of form, recognizing that the conservation of an intact beam is infinitely more valuable than its conversion into dust, both for the economy and for the biosphere.

Regeneration and performance certification

The regeneration and performance certification phase is the technical and legal process through which an element removed from an obsolete building organism officially ceases to be a residue or waste to be reintegrated into the market as a certified construction product (Hradil et al., 2014). In this phase, the recovered raw matter is subjected to an intervention protocol that merges materials engineering, advanced diagnostics, and high-precision industrial craftsmanship, with the objective of closing the qualitative and regulatory gap compared to virgin products (Malhotra & Carino, 2004).

Physical regeneration usually takes place in specialized workshops or authorized processing centers, where the structural component is subjected to treatments that restore its full mechanical functionality and prolong its useful life for additional decades-long cycles. Preliminary operations involve surface remediation; however, the most significant intervention is geometric-structural in nature. At this stage, the reprofiling of the extremities is carried out, an operation necessary to eliminate heat-affected zones resulting from cuts made during the deconstruction phase (Durmisevic, 2019).

From an engineering perspective, regeneration can also include performance-enhancement interventions. If the material audit has highlighted section losses due to localized corrosion or if new project requirements demand a higher load-bearing capacity, structural supports are applied in the workshop. In this way, the recovered material is not merely repaired, but upgraded, transforming an intrinsic limit of used matter into an opportunity for targeted structural optimization (Bungey et al., 2006).

Simultaneously with physical transformation, the technical validation and **recertification protocol is activated**, which is the sole instrument capable of providing the necessary "legal license" for the material to be installed.

From a critical and legal standpoint, this passage raises the complex question of the liability of the certifier and the Technical Director of the processing center. In a regulatory framework like the Italian one (NTC 2018), which places extreme emphasis on traceability and the qualification of materials, the regenerator effectively assumes the responsibilities of the manufacturer. The recovered material attains the status of a "construction product" only when it is accompanied by documentation attesting to its compliance with essential safety requirements. This is a moment of performance certainty: the used beam can now be entered into structural calculation software with the exact same partial safety coefficients as new materials, eliminating any technical prejudice and allowing the static inspector to approve the work with absolute legal peace of mind.

Ultimately, the regeneration and certification phase is the link that transforms ecological aspiration into regulatory rigor. Although the cost of these processes (transport to the workshop, laboratory tests, precision machining) may at first appear higher than the purchase cost of new material, the balance must be evaluated on a global scale (Thormark, 2006).

The savings in CO_2 emissions (up to 95% for steel and 80% for prefabricated concrete) and the reduction in the consumption of raw resources represent an environmental value that, if correctly monetized through carbon credits or fiscal incentives, makes upcycling not merely technically possible, but economically preferable (Crowley et al., 2019). The future challenge for research will be the standardization of these recertification protocols, rendering them streamlined and digitized industrial processes capable of lowering entry barriers for small and medium-sized enterprises in the construction supply chain.

4.2. The logistic - economic deficit

The transition from a linear extractive approach to a fully regenerative model encounters the logistical-economic deficit, a systemic inefficiency generated by the absolute incompatibility between the rhythms of building decommissioning and those of new architectural production. Within a real estate market governed by the dogma of temporal hyper-optimization and the minimization of storage costs, the introduction of unstable, heterogeneous, and geographically dispersed flows of matter disrupts consolidated supply chains, revealing the total inadequacy of contemporary logistical infrastructures.

This deficit manifests primarily as space-time asynchrony: while the linear industry is founded on the predictive punctuality of the Just-in-Time model, the urban mine releases its resources discontinuously, stochastically, and entirely decoupled from demand trends. In the absence of intermediate physical buffers (metropolitan logistical hubs dedicated to the staging, cataloging, and diagnostics of removed materials), recovered matter is rapidly directed toward destruction to avoid costly operational delays at the originating construction site.

To this physical friction is added the economic paradox of "mine costs," whereby selective deconstruction (a craft-based process characterized by a very high intensity of specialized labor) proves financially disadvantageous when compared to the artificially low prices of virgin materials, which benefit from global economies of scale and the failure to internalize environmental externalities.

This double barrier, both administrative and financial, not only renders reuse financially impractical, but favors the proliferation of expedited downcycling practices, utilized as bureaucratic shortcuts to evade the complex management of authentic upcycling and to conceal the dissipation of matter beneath a veneer of superficial sustainability.



Fig. 78_Rotterdam Circular Window Collective, De HER- Rotterdam, 2025. Source: *bam.com*

Spatio-temporal asynchrony and the absence of intermediate buffers

The transition from a linear economic model (structured on the extractive and unidirectional sequence of take-make-waste) to a genuinely regenerative, circular paradigm focused on upcycling collides first and foremost with a primary systemic barrier of an intrinsically logistical, spatial, and temporal nature. Such a barrier is represented by the **structural incompatibility and radical chronological incompatibility** between the obsolescence and decommissioning cycles of the existing building stock and the programming, techno-financial planning, design, and construction scheduling of new building work.

Within the consolidated and hyper-optimized linear industrial paradigm, the entire supply chain relies on the systematic reduction of temporal and spatial frictions through the capillary application of the Just-in-Time (JIT) model (Addis, 2006). This managerial strategy, originally borrowed from the automotive manufacturing sector and subsequently translated into operational practice within contemporary construction, aims to maximize financial efficiency by eliminating the costs of storage, handling, and capital immobilization. In the linear construction site, virgin raw material is manufactured in a factory, shipped, and delivered at the exact moment it must be laid in place, according to a rigidly deterministic chronoprogrammatic sequence. The contemporary construction site, operating in urban contexts frequently characterized by drastic spatial compression, does not possess (and cannot afford to possess) significant physical storage areas; the resource arrives at the productive site as a continuous, synchronous, and pre-certified flow, ready for immediate assembly (Hegger et al., 2006).

This highly predictable, standardized, and synchronous flow remains, however, biologically and technically incompatible with the dynamics controlling the reuse supply chain. Flows of recovered matter, unlike industrial ones, are generated according to extremely discontinuous and unpredictable supply logics, entirely unlinked from the trend and fluctuations of market construction demand. The moment an existing architectural organism reaches the end of its use cycle and undergoes decommissioning (the phase generating the supply of secondary resources) is determined by complex external variables: fluctuations in ground rent, real estate speculation cycles, contractual deadlines, regulatory changes, or municipal-scale urban regeneration plans. Such events manifest according to their individual timelines that rarely coincide with the gestation, executive design, and operational start-up phases of a new project site that could usefully welcome and integrate such components (Durmisevic, 2019). An unbridgeable **temporal fracture** is thus consumed in which supply manifests when demand is not yet mature, or vice versa, triggering constant transactional inefficiency.

Superimposed and welded to this temporal-based asynchrony is a complex **geographical and territorial fragmentation.** The points of origin where the resource to be extracted becomes available (the nodes of the urban mine) and the points of actual reuse are distributed across the territory in a pulverized, inhomogeneous, and random manner. The contemporary urban landscape lacks an infrastructural network, both physical and digital, tasked with mapping in real time the state of consistency of the built heritage close to decommissioning, cataloging its components, and planning their encounter with project demand. A dual and paralyzing misalignment is thus generated: spatial, whereby the physical resource is geographically distant from the place where the construction need arises, and temporal, whereby the resource becomes available at a different time from that required by the stringent timelines of the receiving construction site.

In this scenario of total fragmentation, the systematic absence of intermediate physical infrastructure (the so-called logistical buffers, conceived as integrated metropolitan lungs for temporary storage, advanced diagnostics, reconditioning, and digital cataloging) constitutes the main breaking point, and structural failure of the circular economy applied to architecture. In current building practice, the entire process is weakened by a dramatic "**logistical vacuum**" that cancels out any ambition of upcycling from the outset. The decommissioning construction site operates under conditions of severe temporal and financial compression: every single day of delay in freeing up the urban plot for subsequent reconstruction entails unsustainable economic penalties for the demolition firm.

Without a protected, equipped intermediate space situated at distances compatible with urban logistics, into which dismantled components can be quickly channeled to remove them from the pressure of the originating site, the firm is forced to act according to logics of mere maximization of clearance speed and minimization of immediate cost. Unable to afford to store the matter in situ while waiting for the market to express a specific demand for those batches of material, nor being able to conduct investigations and performance tests on-site, the operator chooses the only economically predictable and tested path: massive, undifferentiated, and destructive demolition, which reduces construction complexity to waste to be directed toward disposal or crushing.

This storage and cataloging vacuum translates into an incalculable ecological, energetic, and tectonic loss. Complex building components characterized by a very high content of embodied energy and considerable residual economic and functional value (such as high-performance wood or aluminum window frames, structural glulam or steel carpentry, natural stone cladding slabs, industrial partition modules, or technological plant elements) are irremediably degraded to the legal and physical status of inert waste (Thormark, 2006). They are fed into the landfill disposal circuit or, at best, undergo indiscriminate mechanical downcycling, being crushed for the production of road aggregates.

The lack of an infrastructure-based operational limbo prevents the ontological and bureaucratic transition of matter from "construction site waste" to "cataloged and tracked resource," fundamentally precluding the possibility of structuring a transparent, reliable, and standardized market for second-hand building materials.

Such logistical vacuum consequently acts as an effective inhibitor of the creative and design process: the architect desiring to practice upcycling lacks a physical catalog or a stable, guaranteed, and accessible digital inventory to draw from during the project development phases. They thus find themselves faced with the technical and legal impossibility of specifying recovered building components in contractual and structural documents whose actual presence, physical integrity, quantity, and performance compliance at the time of installation cannot be ensured in any way, condemning the work to fall back upon the reassuring and tested flows of industrial virgin materials.

The Economic Paradox of Urban Mining and Mining Costs

The concept of Urban Mining represents one of the most evocative and theoretically revolutionary attempts to dismantle the linear ontology of the construction industry, proposing to consider the consolidated city and obsolete building stock no longer as environmental liabilities or waste deposits, but as true anthropogenic deposits of secondary raw materials.

This scientific perspective indicates that the material stock accumulated within our urban areas over the centuries (composed of metals, stone fractions, structural timber, bricks, and polymers) constitutes a resource reserve of extremely high energy and functional concentration, ready to be extracted, regenerated, and reinserted into local production flows without further burdening fragile planetary ecosystems. However, when attempting to translate this ecological transition from a theoretical suggestion into an operational financial model, the direct economic comparison between supply from the urban mine and that guaranteed by classic linear extractive supply chains reveals a strong and structural market distortion (Addis, 2006). This phenomenon, widely studied in applied circular economy, is termed the **“mine cost paradox”** and constitutes the main systemic obstacle to the widespread diffusion of reuse and upcycling practices at a macroeconomic scale.

The deep root of this paradox lies in a structural and seemingly insurmountable technological, organizational, and historical asymmetry characterizing the two industrial models under comparison. On one hand, the linear extractive supply chain and virgin material production benefit from over a century of radical capitalist optimization, massive direct and indirect state subsidies, global economies of scale, and massively automated and standardized manufacturing processes.
The industrial production of primary construction elements demands an extremely reduced direct labor input per unit of finished product, since almost the entire value chain is delegated to machinery with very high thermo-mechanical efficiency, capable of operating on an uninterrupted cycle. This model competently slashes initial production costs and sales prices on the primary consumer market, offloading the economic impact of its ecological-related inefficiencies onto the planet’s future in the form of intensive fossil fuel consumption and climate-altering emissions.

Conversely, the inverse value chain associated with selective deconstruction and the valorization of recovered matter is configured as an almost entirely artisanal, **customized process characterized by a very high intensity of manual labor.** Dismantling an existing building component while preserving its geometric integrity, mechanical properties, and initial aesthetic performance requires planning a slow, methodical, and intrinsically complex construction site, which excludes the use of explosives or heavy mass demolition machinery. This activity demands the employment of highly qualified personnel with specific skills in constructive reverse engineering, able to interpret historical or modern connection systems and operating accuracy tools to disassemble joints without causing fractures in the components (Hradil et al., 2014). The lengthened timelines required for controlled removal, the necessity to conduct preliminary diagnostic campaigns and in situ non-destructive tests to verify the state of preservation of the matter, and the following operations of sorting, cleaning from mortar or adhesive residues, and protective packaging weigh heavily on the overall economic balance of the recovery operation.

In the contemporary market, dominated by consistently high labor costs (especially in Western and European contexts) and artificially low virgin raw material costs, the activity of urban extraction and physical regeneration of existing matter is almost always financially disastrous for real estate developers. The paradox is fulfilled and emerges in all its evidence the moment the purchase of a new, pre-certified, standardized industrial artifact imported from globalized supply chains with low labor costs proves noticeably cheaper compared to the operation of dismantling, proximity transport, reconditioning, and performance recertification of an identical element already present locally on a zero-kilometer basis. An insurmountable barrier to entry is thus created that discourages designers and firms from pursuing reuse, confining upcycling to a niche of high-budget experimental projects or purely demonstrative value.

This macroscopic economic distortion is by no means the outcome of an intrinsic inefficiency nor a technological deficit of the circular paradigm, but rather the direct consequence of a structural failure of the linear market, which deliberately omits to internalize negative environmental and social externalities into the final price of virgin products. The nominal selling price of a primary industrial construction material is partial and distorted, as it consistently excludes the real costs of ecological damages inflicted on natural systems throughout its entire lifecycle: the irreversible destruction of biological habitats during quarrying phases, the loss of biodiversity, chemical pollution of air, soil, and aquifers, health costs linked to emissions of fine particulate matter and toxic gases, the social cost of greenhouse gas emissions produced during the very high-temperature thermal synthesis of materials, and, last but not least, the ecological and transportational cost of future landfill disposal at the end of the use cycle.

This phenomenon allows virgin materials to become competitive in terms of immediate costs only because the economic impact of their ecological footprint is socialized, burdening the community, and postponed in time, leaving the monetary burden of remediation to future generations. If economic calculation models and regulatory systems adopted holistic metrics based on real lifecycle (Life Cycle Costing integrated with Life Cycle Assessment), introducing taxation proportional to embodied carbon or severe penalties on the consumption of non-renewable primary resources, the economic value of recovered materials would be instantly and equitably realigned with that of virgin products. Matter extracted from the urban mine, in fact, having already amortized the ecological consequence and climate-altering emissions of its previous industrial production over the course of the preceding lifecycle, would prove to be the financially most logical, ethical, and convenient choice for any operator in the construction sector (Raga et al., 2021).

It is precisely within this economic convenience that one of the most critical, systemic, and harmful drifts of the contemporary construction sector takes root and proliferates: the systematic and conscious replacement of authentic upcycling processes with expedited downcycling practices, often promoted and celebrated under the mystifying label of avant-garde sustainability, ecological architecture, and certified circular recycling.

Currently, almost all major urban transformation projects emphatically claim the achievement of staggering percentages of demolition waste recovery, frequently exceeding 90% or 95% by weight, confident that such quantitative performance guarantees obtaining the highest scores within international environmental rating protocols such as LEED or BREEAM, as well as automatic conformity with mandatory requirements defined by Minimum Environmental Criteria in the context of Italian public procurement. However, if these triumphant quantitative narratives are subjected to stringent scientific analysis, founded on the principles of thermodynamics and the energy balance of material flows, it turns out that almost all resources physically diverted from landfills actually undergo a drastic, irreversible, and dramatic qualitative, performance, and functional depreciation, configuring a refined form of quantitative and material greenwashing that conceals the destruction of real value behind the virtuosity of numbers.

The most emblematic, widespread, and systematic example of this distortive dynamic lies in the treatment reserved for large quantities of reinforced concrete, bricks, and stone elements from demolitions. Current construction and economic practice responds to the need to clear urban plots in the shortest possible time to initiate new real estate speculation cycles; to achieve this, it relies on mass, undifferentiated, and destructive demolition techniques via the use of hydraulic shears and heavy excavators. The mixed debris thus generated is subsequently subjected to mechanical crushing performed directly in situ by mobile crushers, reducing rubble to heaps of recycled aggregates of varying granulometry, destined for immediate, low-nobility reuse in the form of

road sub-bases, excavation fills, or lean cementitious stabilizations for infrastructural works.

From a physical, thermodynamic, and engineering standpoint, this operation in no way constitutes a valorization of the resource (upcycling), but rather a programmed, inefficient, and irreversible dissipation of its overall use value and its intrinsic exergy. First, a dramatic performance depreciation of the material-system is witnessed. A complex building component that in its original form and constructive configuration expressed high-level static, structural, insulating, acoustic, or aesthetic performance is brutally disaggregated and reduced to an amorphous mass of incoherent aggregate of very low economic and functional value. This disintegration cancels the intrinsic structural order of the element, degrading it from a complex dimensional configuration dense with information to a base matter devoid of any negentropy.

This **loss of functional complexity** is accompanied by the **irreversible reset of all embodied energy and human, technological**, and design labor originally invested in the artifact (Hegger et al., 2006). Manufacturing a complex structural or architectural element requires immense energetic and environmental expenditure for raw material harvesting, industrial refining, thermal molding, global logistical handling, and exacting assembly. When this artifact is crushed to be dumped under a road surface, all this structuring energy accumulated in matter is instantaneously dissipated. If one wished to create an equivalent building component in the future starting from that recycled aggregate, it would be necessary to input a massive quantity of new primary thermal and electrical energy into the system, in addition to new chemical binders with very high emission impacts, such as Portland cement. Concrete downcycling thus proves to be an energetically disastrous operation on a global ecological scale, since it destroys the thermodynamic work consolidated in matter to replace it with a linear process that requires costly compensatory energy inputs to generate new useful matter.

The scientific, political, and legal legitimation of this destructive process is made possible by a serious and persistent methodological error inherent in existing indicators of circularity evaluation and community environmental policies. Sustainability certification protocols and European waste regulations evaluate the effectiveness of circular economy methods relying almost exclusively on a weight-based metric, which quantifies recovery effectiveness based on kilograms or tons of matter diverted from landfills, without making any qualitative distinction regarding the functional destination of recovered resources. This metric distortion macroscopically favors heavier materials with lower technological added value: for the weight balance of an ecological certification, crushing a thousand tons of structural concrete to make a road sub-base is exactly equivalent to saving a thousand tons of high-tech steel beams or wooden structural portals to reintegrate them entirely into a new building.

This quantitative equivalence allows the construction industry to destructively raze entire architectural complexes to the ground (often still sound and eligible for retrofit or selective deconstruction interventions) and present the entire speculative operation as an extraordinary ecological success, concealing behind the formal excellence of recycling percentages by weight the systematic, silent, and irreversible destruction of noble and non-reproducible resources. The generalized reduction of matter to road aggregate thus configures itself as a convenient, profitable, and assuring bureaucratic shortcut for the traditional construction, demolition, and recycling supply chain. This economic model, historically based on execution speed and the movement of large volumes of earth and rubble, invests in heavy, rapid crushing machinery because it guarantees immediate profits with low operational risk. At the same time, it relieves firms from the burden and responsibility of developing non-destructive dismantling technologies, supervising complex proximity reverse logistics platforms, assuming the civil and insurance risks linked to the performance recertification of recovered elements, and training workers in a new construction site culture.

This material greenwashing, institutionalized by current weight-based metrics, effectively perpetuates the exact same extractive, linear, and destructive approach of traditional speculative construction, simply coated with a superficial veneer of facade circularity.

The final result is the **progressive deprivation for future generations of an immense heritage of building components with high architectural, functional, as well as tectonic potential** which, if instead managed through the scientific protocols of Material-led Design, could have been dismantled, regenerated, recertified, and repositioned at the apex of the use-value pyramid, preserving the material identity, tectonic memory, and embodied energy of the existing built heritage.



Fig. 79_De Ceuvel's Downcycling Challenge, Space & Matter- Amsterdam, 2013. Source: *spaceandmatter.nl*

CHAPTER FIVE

05

Strategies for the future: operational protocols and systemic solutions

The analysis conducted and explored in depth in the preceding chapters has made evident an essential fact for the future of the construction sector and urban regeneration: structural upcycling no longer suffers from a real shortage of technological solutions, nor from a lack of aesthetic vision or environmental sensitivity. On the contrary, we find ourselves confronting an operational paradox in which the technical capacity to dismantle, regenerate, and reassemble matter has already reached levels of excellence, yet remains trapped in a serious and ingrained systemic asynchrony. This disjunction is none other than a structural friction between the different speeds moving the construction industry: on one hand, international political will, driven by the urgencies of the climate crisis and European targets on carbon neutrality; on the other hand, the rigidity of national technical standards still anchored to the dogma of virgin material and a supply chain organization stuck in the linear models of the past century.

To transform what today appears as a pathbreaking exception (often relegated to iconic showcase projects or isolated experiments funded by special grants) into a common, consolidated, and above all scalable practice, it is imperative to move from the logic of the episode to that of the system. It is necessary to structure an integrated ecosystem capable of drastically mitigating professional risk for designers, who are currently the first to shoulder the legal questions of reuse, and of breaking down the economic barriers that often render recovered matter less competitive than extracted matter. The challenge is no longer to demonstrate “whether” it is possible to build with waste, but to define “how” to make it the new industrial standard.

The future of circular architecture in Italy, historically characterized by a dense industrial stratification and an avant-garde technological vocation, can no longer dispense with an organic systematization of resources and skills. However, for the city to truly transform into an active and pulsating material bank, it is necessary to overcome the fragmentation of interventions and bureaucratic timidity. This transition toward common practice requires a coordinated strategic action in three areas, simultaneously handling the physical, professional, and procedural dimensions.

First, the creation of **territorial physical infrastructures** (Material Hubs) acting as logistical lungs and validation centers is fundamental. Without a physical place where matter can dwell, be tested, and be cleansed of its legal condition as waste, every design effort will clash with the impossibility of managing construction-site timelines.

Second, the definition and recognition of **new professional figures** endowed with hybrid competencies are necessary: experts capable of navigating with equal ease among material diagnostics, environmental jurisprudence, parametric design, and flow logistics.

Finally, the codification of **clear, safe, and reproducible operational protocols** is indispensable, offering the design studio a technical and legal compass to navigate between the constraints of the procurement code and the opportunities of structural recovery.

In this concluding chapter, we therefore intend to outline the guidelines for a new normality of designing and building. Only through the synchronization between physical space, regulatory framework, and specific competence will it be possible to definitively transform the industrial wreck into a valuable civil resource.

The transition from a heroic and individual practice to a common and collective practice is the only way to make upcycling the qualitative standard of future Italian regenerative architecture, making certain that every ton of steel or concrete extracted from our past is not lost, but becomes the mining capital upon which to base the aesthetic and security of the cities of tomorrow.

Critical synthesis: the feasibility of upcycling

The research conducted throughout this treatise commands a critical and rigorous assessment that discards easy rhetorical enthusiasm: at the current state of the art, the practice of upcycling at an architectural scale is not fully feasible.

Although the analytical decomposition of the mechanical properties of recovered materials and the examined environmental evaluations (LCA) confirm an in vitro scientific validity, the application of such processes in the real sector of construction production clashes with an industrial reality that is entirely unprepared and hostile. The design and computational tools available to the architect, though advanced, remain restricted to the domain of theoretical speculation or isolated experimentation.

The transition toward a widespread model of Urban Mining is not simply slowed down, but finds itself in a state of true **operational paralysis** caused by deep structural asymmetries that make the practice systematically unfeasible for standard construction channels. The most significant outcome of this study lies precisely in the deconstruction of the myth of immediate feasibility: architecture cannot become regenerative solely through the designer’s willpower. Today, a project entirely based on the principles of Material-led Design or structural upcycling is destined to founder against the rigidity of a supply chain conceived exclusively to protect the linear extractive model of virgin matter.

For this procedure to transition from academic exceptionality to the reality of the construction site, the implementation of **big structural changes of a legislative, regulatory, institutional, and administrative nature** is indispensable and urgent. Without a thorough rewriting of these systemic rules, upcycling is destined to remain a sterile utopia. Specifically, the factors determining the current unfeasibility of the discipline are articulated along four macroscopic fronts of inertia:

- Legislative and Legal Barriers:
Environmental legislative structures systematically and penalizingly assimilate the post-consumer resource into the legal regime of waste. The root of this conflict lies in the very setup of environmental consolidated acts, created to sanction and curb illicit disposal rather than to incentivize industrial symbiosis or architectural recovery. The paradox of current regulations effectively prohibits the direct transit of components from one construction site to another, freezing matter in a bureaucratic limbo. The moment a structural or finishing element is removed from its original positioning, it instantly loses its status as a product and acquires the EWC (European Waste Catalog) code. To re-enter the economic cycle as a valid construction material, the element must undergo End-of-Waste procedures that are so complex, punitive, and devoid of specific secondary legislation for the construction sector that they indefinitely dilate construction site timelines. This regulatory void exposes companies to severe risks of criminal sanctions for unauthorized waste management, legally forcing them to prefer the linear and stable path of landfill disposal or thermal destruction, making structural upcycling an administratively unsustainable gamble for any economic operator.

- Regulatory and Certificative Anomalies:
From a technical standpoint, systemic frictions manifest in the absolute rigidity of performance validation protocols and commercial quality marks, such as CE marking, which are structurally calibrated on homogeneous, stable, and predictive series productions. The entire framework of Technical Regulations for Construction and the Construction Products Regulation (CPR 305/2011) presupposes an industrialized model in which the manufacturer guarantees the performance constancy of a batch through destructive laboratory tests on statistical samples. Current legislation does not provide any flexibility to accommodate the intrinsic variability, anisotropy, and natural aging of recovered matter, whose properties must be verified element by element. This total asynchrony between prescriptive law and the nature of waste creates a responsibility vacuum: in the absence of uniform marking, testers and construction managers find themselves legally unable to authorize the extension of the useful life of components within primary or secondary structures. The risk of performance defect

is not covered by traditional insurance policies (such as post-construction decennial liability), leading to the definitive rejection of the material by contracting authorities.

• Institutional and Logistical Inadequacy:
The contemporary city, despite theoretically being an immense mining deposit with a high density of embodied energy, simultaneously denies the physical spaces and institutional channels necessary to govern material flows in a circular key. The current urban development model conceives the construction site as an isolated entity rather than the node of an interconnected metabolic network. There is a complete lack of a proximity logistical network capable of managing the temporal asynchrony between the selective demolition phase of a donor building and the construction phase of a receiving organism. The chronological coincidence between supply and demand for waste is a statistically unusual event, and the real estate market of dense metropolitan areas penalizes large horizontal spaces economically, making the cost of land for long-term storage prohibitive. At the same time, there is a total absence of public material banks or institutionalized intermediate storage hubs. Such structures should not be configured as inert collection centers, but rather as advanced logistical infrastructure dedicated to digital cataloging, remediation from historical toxic substances (Legacy Materials), alongside proximity recertification of extracted components, without which long-range transport of the circular resource would end up nullifying the global environmental balance expressed in terms of Embodied Carbon.

• Economic and Professional Factors:
The real estate financial market expresses a net preventive refusal toward upcycling due to the predictive indeterminacy of estimate metric calculations, which remain structurally unstable until the actual retrieval and validation of the waste. Traditional economic calculation algorithms and regional price lists are calibrated on the fixed costs of industrial catalogs; in the recovery project, however, the cost of the material is zero or reduced, yet heavily burdened by the economic unknowns linked to labor for surgical removal, reverse logistics, and laboratory testing. This inversion of the cost structure frightens institutional investors, who demand strict financial certainties before the opening of the construction site. Added to this economic barrier is the atrophy of the professional skills of construction site workers, the final link in the executive chain. The progressive industrialization and simplification of construction processes have turned construction workers into passive installers of pre-assembled catalog systems, leading to the loss of tectonic knowledge, artisanal sensitivity, and empirical knowledge of matter necessary to operate non-destructive surgical deconstruction and the subsequent morphological adaptation of recovered elements.

5.1. Material-led-Design

Material-led Design represents a true Copernican revolution in the approach to contemporary architectural creation.

For centuries, the established practice of Western architecture (from Renaissance idealism to international modernism) has understood design as an act of intellectual domination: the imposition of an ideal form, born from the abstraction of drawing, onto matter considered servile. In such a linear scheme, the choice of material usually occurs downstream of spatial definition. The architect designs within the reassuring void of the tabula rasa, defining structural spans, heights, and aesthetic languages, only to draw from a theoretically infinite catalog of virgin and standardized resources capable of guaranteeing certain performance and unlimited availability. Structural upcycling, conversely, demands that the terms of this equation be drastically inverted: it is no longer the design that determines the material, but rather the physical, finite, and immediate availability of matter that dictates the rules, dimensions, and ultimate possibilities of the design.

This reversal fundamentally dismantles the very concept of architectural invention. The starting point is a pre-existing physical component that carries with it a non-negotiable heritage. In such a context, the architect's creativity lies in the critical ability to resolve the constraint.

Adopting Material-led Design also means accepting a new aesthetics of contingency. Since the urban deposit never offers perfectly identical elements or in constant quantities, the designer must relinquish total control over the repeated detail, embracing heterogeneity as a tectonic value. The value of the work resides in the curator-like wisdom with which obsolete resources extracted from the urban metabolism are orchestrated into a new structural synthesis.

Designing with what is already present is the political act of restoring dignity to sequestered matter, transforming obsolescence into a generator of new urban identity.

Fig. 80_ Circl Pavilion as a temporary material bank, de Architekten Cie- Amsterdam, 2017. Source: *divisare.com - Ossip van Duivenbode*

From geometric abstraction to material constraint

The transition from geometric abstraction to material constraint marks the boundary between architecture understood as a pure exercise of style and architecture understood as the ethical and responsible management of Earth's resources.

In **traditional design**, which we might define as demiurgic in nature, the architect operates under a condition of almost absolute freedom, nourished by the absence of friction between the idea and its physical realization. In this scenario, form is conceived in the pneumatic vacuum of theory, where volumes, structural spans, and aesthetic languages are projected onto an ideal and infinite ground. Matter intervenes only at a later stage, almost as a servile accessory: the designer browses industrial catalogs of virgin matter with the certainty that the market will supply exactly what the drawing requires, in unlimited quantities and with standardized performances that cancel out any unforeseen events. This reassuring linearity, however, hides a critical trap: it produces an architecture that systematically ignores the energy already spent and the value of the materials that the city has already produced, incorporated, and, finally, discarded.

Material-led Design demolishes the root of this presumed omnipotence of drawing and replaces it with a practice of listening to matter. Designing "from below" means accepting an immediate physical challenge, shifting the creative act from the aseptic drafting table to the recovery construction site or among the laser scans of an industrial skeleton. Here, the starting point is no longer the straight line drawn on software, but the encounter with an existing physical component that possesses its own stubborn identity, its own chronology, and its own non-negotiable resistance.

This condition radically transforms the project into a tight and **cultured negotiation with reality**. The material constraint becomes the primary engine of creativity, the regulator that prevents formal arbitrariness. Architectural form is the honest and necessary result of a work of conscious assembly.

Every dimension of the new building is dictated by the measure of the recovered piece; every structural span is calibrated to the residual load-bearing capacity of the component; every joint becomes the visible narrative of a technical adaptation between two different eras.

The architecture that emerges from this process renounces the polished and anonymous perfection of factory-new materials to adopt a **tectonics of assembly**, where value lies in the designer's ability to recompose finite fragments into a new, structurally safe, and spatially coherent organism.

Interpreting this passage means understanding that the architect is no longer the one who commands matter, but the one who organizes it.

Material-led Design restores a **simultaneously artisanal and industrial dimension** to the discipline, where the constraint of existing matter is not an obstacle to progress, but the only true scientific and poetic basis upon which to found a new aesthetic of lastingness and urban regeneration. Ultimately, the resulting form of upcycling does not celebrate the designer's ego, but the strength of the resource, making visible the technical intelligence required to subtract value from obsolescence.

The aesthetics of contingency

Adopting the paradigm of Material-led Design means, first and foremost, embracing and ennobling what we might define as an aesthetics of contingency.

In standard architectural culture, aesthetics has often been understood as the achievement of a predefined ideal, a static and crystallized image to which material reality must slavishly adapt. However, the moment recovered matter ceases to be an exception and becomes the primary driver of the process, this dogmatic certainty vanishes. The resource extracted from the urban fabric is never perfectly standardized, nor available in infinite quantities or constant flows; it bears the mark of time, the unforeseen events of the deconstruction site, mechanical wear, and intrinsic heterogeneity. Consequently, the design act must abandon its predetermined rigidity to acquire an ontological flexibility, an adaptive capacity that traditional design, nourished by the industrial just-in-time supply of virgin matter, has never needed to develop.

This radical shift in theoretical and operational perspective inevitably leads to the genesis of the **open project**: an architectural system conceived not as a finished and immutable object, but as a resilient organism capable of absorbing the variations and surprises stemming from the material deposit throughout its entire realization cycle. This is a profoundly transformative working methodology: if during the delicate phases of selective dismantling or laboratory structural diagnostic sessions a series of columns or trusses proves unsuitable for full reuse, the overall design must possess sufficient **elasticity** to allow an adjustment of the grid or a variation in configuration without the entire conceptual apparatus being affected. In this scenario, the project is a dynamic assembly strategy capable of reacting in real time to the actual availabilities of the urban mine.

The aesthetics of contingency celebrates **constructive honesty** by bringing to the fore what is usually concealed. Structural nodes, bolted mechanical joints, steel reinforcement plates, and material hybridizations between components from different chronological eras cease to be simple technical details and become the primary decorative and functional elements of the work. It is an architecture that does not fear the technical scar or the chromatic discrepancy between a 1950s metal profile and a contemporary integration, but makes it an expressive strength, a visible palimpsest of its own production history.

Exploring this concept implies acknowledging that the open project acts as a mediating device between past and future. Dry-assembly joints, necessary to ensure reversibility, become the manifesto of a new ethics of building: every visible bolt testifies to the option of further dismantling, guaranteeing that the material is never again sequestered in an irreversible form. This approach requires the designer to have an almost curatorial sensibility: they must **design for tolerance**. Tolerance becomes the margin of maneuver where the imperfection of the recovered component encounters the accuracy of the new intervention, creating a meaningful aesthetic tension.

Ultimately, this aesthetics finally makes the invisible visible and communicable: the immense effort of energy saving and the conservation of raw materials accomplished by the upcycling operation.

The building is a physical narrative of its own regeneration, where each component recounts its provenance and its redemption from obsolescence.

The open project therefore does not represent a renunciation of formal quality or a fallback due to scarcity, but the conquest of a new ethical and performative beauty. In this system, architecture renounces the self-referentiality of the sign to become a responsible interpreter of the metabolism of urban resources.

New professional figures

The reversal of the design process imposed by Material-led Design is not limited to a chronological reorganization of work phases, but radically shifts the axis of responsibility, ethics, and the very identity of the architectural profession.

In this new paradigm, the architect undergoes a major and necessary metamorphosis: they cease to be exclusively an author of forms (a figure traditionally linked to solipsistic aesthetic intuition and volumetric composition generated in the pneumatic vacuum of the tabula rasa) to evolve into a curator of material flows. This transition reflects the inescapable shift from a linear construction economy, based on the extraction-production-waste cycle, to a circular one, where value no longer resides in the consumption of land and raw resources, but in the intellectual and technical capacity to intercept, redirect, and ennoble materials already saturated with embodied energy within the urban metabolism.

This new professional figure must possess and coordinate **cross-disciplinary competencies** that far exceed the classic academic baggage of the twentieth-century architect. Material curation requires, first and foremost, the **ability to engage in a symbiotic dialogue with the most advanced engineering diagnostics.** It is no any longer just a matter of calculating loads and stresses on new materials, whose technical data sheets are pre-certified by the manufacturer, but of validating unique pieces laden with history, micro-cracks, and possible signs of fatigue. The architect-curator must know how to interpret degradation maps, non-destructive ultrasonic testing, chemical analyses on surface oxidations, and structural durability tests. They effectively become the technical and moral guarantor of the static safety of components that current legislation, still anchored to a linear vision of production, would lazily tend to classify as simple waste to be disposed of in landfills.

Alongside this diagnostic sensibility emerges the need for unprecedented **logistical mastery** in the field of civil design. Designing with structural reuse means managing an intricate temporal asymmetry: the availability of matter is dictated by the dismantling timelines of an existing building, which rarely coincide with the construction schedule of the new architectural organism. The architect must therefore transform into an orchestrator of complex processes: they must oversee selective dismantling (a surgical operation very different from indiscriminate demolition), manage transport flows to temporary storage centers, and plan the maintenance or restoration of components awaiting re-integration. From this perspective, the construction site ceases to be a place of pure mechanical assembly of new components and becomes a laboratory for resource regeneration, where the time of logistics and material quarantine becomes a design parameter just as fundamental as space and light.

An additional level of complexity, often underestimated but decisive for the feasibility of upcycling, is represented by the **confrontation with bureaucracy and the regulatory framework**. In a legislative system that is frequently rigid and not yet fully aligned with European directives on circularity, the architect-curator acts as a legal mediator and a regulatory pioneer. They must be capable of managing component recertification processes (so-called re-rating), negotiating the intricacies of technical procedures to legally transform a waste element into a certified construction product pursuant to the CPR regulation. The architectural project consequently alters its documentary nature: it is no longer only a set of descriptive graphic plates, but a complex validation and traceability protocol. Every joint, every beam, and every column is accompanied by a digital passport or a technical identity card attesting to its provenance, residual performance, and suitability for a second functional life, guaranteeing the future serviceability of the work.

The materials auditor

The Materials Auditor represents the frontier figure who intervenes in the earliest and most key phase of the circular value chain. Their role must not be confused with that of a waste management technician or a simple appraiser; they are, to all intents and purposes, a professional capable of looking beyond the aesthetics of decay to track the residual structural potential of a building organism. Their primary task is the execution of the pre-demolition audit, a thorough analytical process that aims to separate what is destined for disposal from what can and must be ennobled through upcycling.

This professional figure must possess deeply hybrid and cross-cutting competencies. On one hand, a solid historical culture of building technology is necessary: the Auditor must be able to read the stratifications of a building, date the components, and, based on the construction era, understand the likely chemical-physical characteristics of the earliest materials.

On the other hand, this historical sensitivity must be supported by an exceptionally high mastery of surveying and non-destructive diagnostic tools. The use of laser scanners for the millimetric restitution of geometries is fundamental to integrate the component into a BIM model; the employment of thermography makes it possible to identify thermal bridges or invisible detachments; the use of covermeters, ultrasounds, or sclerometric tests allows one to see inside heavy structures without damaging their integrity.

A primary aspect distinguishing the Materials Auditor is the ability to evaluate the disassembly potential of a construction system. Not all matter present in an industrial site is worthy of recovery: the Auditor must be able to distinguish with precise accuracy between an element whose extraction would entail an excessive expenditure of energy and labor (rendering the operation ecologically and economically disastrous) and an element that, thanks to mechanical joints (bolting, interlocking connections, dry joints) or favorable dimensional characteristics, can be removed with ease and integrity. This analysis of node reversibility is that it changes brutal, undifferentiated demolition into selective deconstruction, in which every shear stroke or unscrewing is targeted at preserving value.

The Auditor also acts as a risk analyst. They must identify early on the presence of hazardous substances or contaminants (such as asbestos, lead, or PCBs) that could render recovery not only illegal, but dangerous for public health. Their ability to map harmful substances in the preliminary phase allows for the planning of targeted remediation, isolating noble materials from the risk of cross-contamination during construction phases.

The final result of this complex investigative activity is the **Resource Inventory,** a strategic document possessing a dual valence, both technical and legal. First, it provides the designer with a palette of real components, endowed with certain dimensions and performances, upon which to base the new architectural intervention. Second, the Inventory acts as a device of ontological and legal transformation: the building slated for demolition officially ceases to be an environmental liability—meaning a mere disposal cost and a volume of waste—and is legally reclassified as an urban mining deposit.

The Auditor is therefore the primary guarantor of the quality of this deposit, guaranteeing that the territory's industrial past still possesses all the credentials to become the load-bearing, safe, and sustainable pillar of the architecture of the future. Without their scientific analysis, structural upcycling would remain an act of faith; with their work, it becomes a rigorous industrial procedure.

The Reclaim Manager

If the Materials Auditor acts as a prospector extracting value from the industrial past, the Reclaim Manager is configured as the architect of the process, a figure projected toward the future and systemic integration. This profession, which can find a place within avant-garde design firms, engineering companies, or public contracting authorities, assumes the responsibility of managing the most critical and delicate point of the entire circular supply chain: the **strategic matching between the availability, frequently fragmented and aleatory, of recovered materials in the territory and the strict performance, aesthetic, and chronological needs of the new building organism**. They are, to all intents and purposes, the guarantor of the project's circularity, the person tasked with transforming a noble ecological declaration of intent into a solid, certified, and competitive structural reality on the market.

While the traditional architect limits themselves to consulting industrial catalogues of standardised and always-available products, the Reclaim Manager constantly interrogates the Resource Inventory and dialogues with the Territorial Material Hubs. Their role is to synchronise two realities that are rarely contemporary: the decommissioning of the donor building and the construction of the receiving building. This synchronisation is fundamental for reducing storage costs and making sure that the promised material arrives at the construction site exactly when needed, after having undergone the necessary regeneration processes. In this sense, they supervise workshop manufacturing phases (such as cryogenic sandblasting, customised laser cutting, or structural reinforcement of profiles), ensuring that each component is not only physically suitable but also accompanied by its essential documentary and digital apparatus.

The competencies of the Reclaim Manager are intrinsically hybrid and must range from technical management to environmental jurisprudence, up to knowledge of insurance operations. In a complex juridical context such as the Italian one, characterised by a rigid distinction between product and waste, they are the pilot who navigates expertly between End-of-Waste decrees and byproduct procedures, providing the legal foundations so that the use of recovered components is not blocked by bureaucratic fears or sanctions.

In a structural upcycling construction site, the Reclaim Manager assumes the role of a true operational director. Unlike virgin material, recovered matter carries a biography made of imperfections, dimensional variations, and past histories: the Reclaim Manager must possess the managerial readiness to handle the organisational contingencies typical of used matter. If a batch of beams presents an unforeseen discrepancy compared to the initial survey, they must dialogue with structural engineers to find adaptive solutions in real time, preventing the construction site from suffering costly delays. Their problem-solving ability transforms the intrinsic uncertainty of recovery into a fluid and industrial process, reducing professional risk for the design firm and direct liability for the client.

Besides technical management, the Reclaim Manager is also the custodian of the operation's economic value. Through Life Cycle Costing (LCC) analyses, they demonstrate how recovery can become advantageous compared to purchasing new materials, especially in a global market characterised by the volatility of virgin raw material prices.

Ultimately, without this figure, structural upcycling would remain restricted to the domain of heroic craftsmanship or academic experimentation, discouraging major investors and public administrations. With the Reclaim Manager, however, material regeneration enters the era of professionalisation. They are the guarantor that allows the city to stop consuming external resources and begin valuing, with scientific rigour and managerial creativity, its own material memory.

Transversal skills

The profile of the circularity professional is not exhausted in a single sector specialization, but is configured as a hybrid technical entity, a sort of universal translator capable of moving nimbly between the material concreteness of construction site diagnostics, the digital abstraction of information models, and the formal rigor of jurisprudence. For the Materials Auditor and the Reclaim Manager, cross-cutting competencies do not represent a mere accessory kit, but the true added value of their profession: they constitute the scientific and legal infrastructure necessary to transform a practice commonly regarded as artisanal or experimental into an error-proof industrial process, replicable on a large scale. Without mastery of this set of common tools, structural recovery would remain a high-risk gamble; with them, it becomes a rigorous and legally unassailable engineering discipline.

The first essential pillar of this professionalism is **absolute mastery of BIM (Building Information Modeling)** and the digital data flows correlated to it. In a modern circular economy, recovered materials exist, are traceable, and are effectively usable only if they have been previously dematerialized into bits.

The Auditor and the Reclaim Manager must be able to generate and feed the so-called **Material Passports**, dynamic digital containers that accompany the element throughout its entire second life. In this way, the recovered component ceases to be an unknown and becomes a Digital Twin that the structural engineer can insert into their calculation models with the same documentary and statistical security with which they would use a virgin profile directly from a rolling mill.

The second pillar, equally critical and often underestimated, concerns **environmental jurisprudence and deep knowledge of the national and European regulatory framework**. In a stratified legislative context like the Italian one, the demarcation line between construction product, byproduct, and waste is extremely thin, slippery, and dense with criminal and civil implications. This legal-technical competence is fundamental to protect the design studio and the client from administrative sanctions or, worse, from construction site shutdowns due to incorrect classification of the urban deposit. Knowing how to create a byproduct management plan, how to manage reverse logistics without running into the crime of illicit waste trafficking, and how to certify the compliance of a regenerated beam pursuant to the Construction Products Regulation (CPR 305/2011) is what guarantees the economic security of the work. The professional must be able to provide consulting that transforms bureaucratic uncertainty into a fluid authorization pathway, making the project bankable in the eyes of investors and credit institutions.

Beyond this, these figures must develop **avant-garde diagnostic sensitivity** that unites theory alongside empirical field practice. The skill to interpret the results of sclerometric tests, ultrasound, magnetoscopy, or thermographic analyses must not be limited to the cold reading of a laboratory report, but must translate into a critical evaluation of residual potential and expected useful life. Cross-cutting competence manifests here in the ability to decide whether an element is worthy of being regenerated or if the energetic and environmental cost of its restoration exceeds the benefit of recovery.

Ultimately, this set of cross-cutting competencies forms a professional capable of acting as a true **Urban Resilience Consultant.** It is a figure who does not limit themselves to drawing or cataloging, but who manages the complexity of information and the certainty of the norm in a world that is exhausting virgin raw materials. Training technicians capable of integrating diagnostics, BIM, and law means equipping the market with a new technical ruling class, capable of transforming recovered matter into a safe, traceable resource perfectly integrated into the most advanced construction processes of the 21st century, elevating the practice of reuse to a qualitative standard of excellence.

5.2. Construction site operations protocol

The transition toward an authentically circular construction model requires the codification and implementation of a new value chain that diverges radically from the one that has dominated the construction industry over the past century.

The standard linear paradigm, synthesized in the dissipative cycle of “extraction-production-construction-demolition-waste,” is today challenged by the immediate need for environmental resilience plus resource scarcity, and is being replaced by a closed and integrated cycle.

However, even though theoretically every building is a resource, in practice never all construction systems of the past were designed to be disassembled. The challenge of the new value chain is therefore also that of being able to operate a brutal yet necessary selection between what is technically recoverable and what, unfortunately, is destined to remain waste due to short-sighted original design.

The new value chain must consequently shoulder an additional burden: the production of proof of safety capable of convincing not only the structural engineer, but also the insurance adjuster and the public official.

Every phase of this pathway, from initial mapping to surgical deconstruction, from quarantine logistics to performance regeneration in the workshop, constitutes a vital link in a system that aims to remove the very concept of waste. Here, a further critical point emerges: economic sustainability. Selective deconstruction requires lengthier timelines and more specialized labor in comparison to traditional demolition. If the market does not begin to correctly price the positive externality of CO2 savings or heavily tax landfill disposal, the cost of recovered material will always risk being higher than that of virgin material, rendering the entire supply chain structurally fragile from a financial standpoint.



Fig. 81_ People’s Pavilion, Overtreders W e bureau SLA- Eindhoven, 2017. Source: *archdaily.com - Filip Dujardin*

A. The Material Audit and the mapping of urban deposits

In this context, diagnosis is radically redefined: whereas in the classic linear model the pre-demolition survey is a purely dimensional and quantitative operation (aimed almost exclusively at calculating volumes of rubble to be disposed of or managing the logistics of landfill fees), from the perspective of the circular economy it transforms into a true **clinical inspection of matter**. The architect and structural engineer must here abandon the role of simple surveyors to wear the clothes of urban miners, subjects capable of reading the building no longer as a unitary volume destined for disappearance, but as a complex assembly of discrete, stratified resources endowed with a still-active mechanical biography.

The mapping of urban deposits must aim at qualifying residual performance. This implies a strong perspective reversal: the structural component is no longer evaluated for its current function, but for its capacity for the future. The audit requires a systematic and granular census, where each part is cataloged according to a taxonomy that includes typology, millimetric dimensions recorded, state of surface integrity, and, above all, degree of accessibility and dismantlability.

A critical point of this phase is the **analysis of connections**: the auditor's ability to differentiate between bolted joints (easily reversible), welded ones (requiring regulated thermal cuts), or embedded ones ultimately determines the economic feasibility of the entire process. A perfectly sound beam, but embedded in a high-strength concrete pour, might have a null recovery value compared to a bolted component of equal performance, due to the energy required for extraction.

From a critical standpoint, the material audit must face the challenge of **structural invisibility and the uncertainty of historical data**. While in an exposed metal skeleton the survey is immediate, in reinforced concrete structures or heavily paneled industrial buildings, identifying the mine requires the use of non-invasive technologies (Non-Destructive Testing). To reduce the risk of "false positives" (i.e., deposits that reveal occult pathologies only after unsealing), the audit must integrate **in situ chemical-physical investigations**: hardness tests (Leeb or Brinell) for steels, essential for estimating their tensile strength; carbonation tests for concrete; covermeter surveys to map reinforcing bars; and portable spectrographic analyses to determine alloy composition, vital data for establishing future welding protocols.

A key step of the audit is the **search for contaminants**, such as asbestos or heavy metals absorbed during industrial production cycles. This information remediation ensures that only sound and technically clean material can proceed along the value chain. There is an ethical-professional imperative here: everything that does not meet certain safety standards must be honestly and rigorously downgraded to recycling (downcycling) or controlled disposal. Structural upcycling cannot afford diagnostic shortcuts, because a single defective component would pollute the legal credibility of the entire reuse market, frightening investors and insurers.

The final product of this phase is a dynamic digital inventory that directly feeds the BIM libraries of the new project.

This process prompts a reflection on design flexibility: the architect of reuse must accept **heterogeneity** and **imperfection** as **aesthetic values and construction constraints**, transforming the industrial wreck into a logistical warehouse of excellence that takes advantage of the embodied energy already invested in the past for the needs of the future.

B. Selective dismantling

In contrast to traditional demolition, which operates according to a logic of accelerated and undifferentiated annulment of the artifact, reducing it to heaps of post-consumer rubble, selective dismantling is configured as a **surgical, analytical, and intrinsically reversible operation.**

The main goal is the separation of structural components while preserving intact their form, geometric integrity, and, above all, internal mechanical properties. Each element must be extracted as if it were a piece of an assembly kit ready for future reconfiguration, preventing the stress induced by dismantling operations from generating micro-cracks or permanent plastic deformations.

This phase requires highly specialized labor and meticulous engineering planning, which must necessarily include the study of structural stress-release sequences. Deconstructing a building means, in fact, **reversing the loading process**: each removed element alters the static equilibrium of the remaining structure. Without a dynamic shoring plan and a rigorous temporal sequence, the risk is that of triggering sudden collapses that not only jeopardize workers' safety but can irremediably compromise the quality of the components yet to be extracted. Selective dismantling is, in this sense, an exercise in reverse engineering where the understanding of the work's system-wide behavior is fundamental to isolating its individual parts.

For metal structures, which represent the prime deposit for upcycling, dismantling is divided into differentiated procedures depending on the nature of the structural nodes. In the case of bolted joints, the operation involves the controlled removal of bolts using torque wrenches or impact drivers, protecting the integrity of the flanges and webs of the profiles. Whenever working on welded joints, typical of twentieth-century large-scale industry, the approach becomes more complex: precision thermal cuts (via oxy-fuel cutting or plasma) are utilized, performed along the first weld seams or at predefined points that allow subsequent regeneration of the profile head in the workshop. In both cases, the imperative is to minimize the thermal alteration of the heat-affected zone (HAZ), so as not to degrade the metallurgical characteristics of the steel.

The treatment of precast concrete poses equally arduous challenges, requiring the detachment of wet or mechanical joints through the combined use of core drills, diamond disc cutting, or controlled-pressure hydro-demolition. This latter technique is especially precious as it allows the removal of restorative concrete without affecting the reinforcement bars or the profiles of the main components. Selective deconstruction thus becomes the political and technical act in which the embodied energy contained within the material is concretely safeguarded. Every avoided blow of the demolition shear, every cubic meter of concrete left uncrushed, and every ton of steel diverted from smelting represent a net saving of CO_2 emissions as well as a direct gain in terms of material capital already available.

From a critical standpoint, it must be emphasized that selective dismantling still suffers from a **strong economic disproportion** in comparison to traditional demolition. The cost of qualified labor and the extended schedules of the surgical construction site are often seen as insurmountable barriers in the conventional real estate market. However, if one were to begin internalizing within the economic calculation the value of the recovered components (which cease to be a disposal cost and become a sales revenue) and the social cost of avoided carbon, deconstruction would appear as the only economically rational path.

A contractual paradigm shift is therefore necessary: the demolition contract must transform into a resource extraction contract, where competence in preserving value is remunerated more than speed in destroying it. Only in this way will deconstruction cease to be a pioneering exception and become the operational practice of a new conscious architectural season.

C. Reuse logistics

In contrast to traditional construction, where procurement follows a just-in-time logic based on readily available industrial catalogs and unlimited stocks of virgin raw materials, structural upcycling depends on the erratic, fragmented, and geographically dispersed availability of urban deposits. In this context, the storage phase ceases to be a mere passive halt in a warehouse, transforming instead into a period of critical informational management, where the physical preservation of the component must proceed hand in hand with the protection and updating of its digital integrity.

The concept of "**technical quarantine**" best defines the complexity of this phase. When a structural component is removed from its site of origin, it enters a bureaucratic, legal, and technical limbo where it must undergo strict approval procedures before it can be officially reintroduced to the market. During this quarantine, the raw data collected during the preliminary material audit are cross-referenced, verified, and integrated with the specific performance requirements of the new destination project. This is a moment of extreme delicacy in **performance matching**: it is verified whether that specific beam, with its determined technical biography and years of cyclic loading, still possesses the necessary safety margins for the required new static configuration. From a critical perspective, it must be emphasized that if this informational bridge is interrupted due to poor logistical management, the material instantly loses its use value and ontologically regresses to the state of waste, since no structural calculator would accept assuming civil and criminal liability for employing a component whose performance history has become uncertain, fragmented, or, worse, undemonstrable.

To prevent this downgrading, the execution of **advanced tagging systems** (such as laser-etched QR codes, high-frequency RFID tags, or NFC sensors) becomes the enabling and essential infrastructure. Every piece must be physically labeled in an unerasable manner so that, at any moment of logistical handling (from loading onto the articulated lorry to handling via overhead crane, up to rack storage), it is possible to instantly trace its Digital Twin.

A further critical analysis shows that the logistics of reuse require **physical infrastructures** radically different from conventional construction warehouses. Vast spaces are needed, equipped with heavy lifting systems and located in strategic peri-urban areas that act as consolidation centers. Logistics must therefore be rethought as a public service or a public-private partnership, aimed at creating urban lungs of matter capable of absorbing sudden supply and releasing it gradually according to market needs.

Physical safekeeping during storage is another point of extreme technical vulnerability that requires in-depth examination. Recovered materials, once deprived of their original protective coatings, paneling, or infills that protected them for decades, suddenly become exposed and vulnerable. It is essential that the logistic center offers spaces with controlled humidity and temperature to prevent accelerated corrosive phenomena. Technically inappropriate storage can invalidate months of detailed audit and surgical deconstruction work in just a few weeks.

Ultimately, logistics, acting as a strategic accumulator, allows for the creation of physical libraries of excellence components, making them readily available for a plurality of architectural interventions distributed across the territory. This system allows for **price stabilization**, the standardization of certification protocols, and the provision of supply guarantees to builders, drastically lessening the perception of risk linked to the uncertainty of procurement timelines.

URBAN FLOW PLANNING

From a thermodynamic standpoint, upcycling retains its ecological-related effectiveness only if transportation and handling processes do not produce a carbon footprint (Embodied Carbon) higher than the savings derived from avoiding the use of new matter. The overall environmental balance of a reused material cannot be evaluated exclusively at the factory gate (cradle-to-gate), but must necessarily include the entire dimensional and kilometer extension of the reverse logistics chain. In the contemporary heavy mobility model, still heavily dependent on fossil fuel power, the road transport of bulky materials or materials with high mass density (such as reinforced concrete structural elements, profiled steel beams, or massive stone building blocks) generates climate-altering emissions that grow exponentially as a function of the distance traveled.

If the territorial procurement radius of the waste exceeds a certain space-temporal crucial threshold, the impact generated by transport flows ends up neutralizing or even surpassing the ecological benefits derived from avoiding the extraction of raw resources from the natural environment, converting the entire upcycling operation into a glaring ecological paradox. Environmental efficiency thus ceases to be an intrinsic, fixed, and immutable attribute of recovered material and instead becomes a fluid variable, directly dependent on the geographical, infrastructural, and logistical structure of the territory in which one operates.

Current construction models nevertheless suffer from an intrinsic temporal asynchrony between the moment of waste availability and that of real need on the construction site, aggravated by the chronic scarcity and high cost of physical spaces necessary for storage inside dense cities. The contemporary city still operates according to a linear and deregulated metabolism, within which the lifecycles, obsolescence, and transformation phases of individual building organisms are completely disconnected from one another from a temporal perspective. The spontaneous chronological coincidence between the selective demolition act of a "donor" construction site and the foundation or structural elevation phase of a new "recipient" construction site constitutes a statistically uncommon and random event. This systematic temporal misalignment requires a staging or intermediate buffer phase for the extracted matter, so that it is not lost.

However, the densely built urban structure of metropolitan areas expresses a radical and structural spatial incompatibility with the on-ground storage requirements of heavy and bulky material flows. In contemporary cities, urban suum is an extremely scarce resource subject to intense monetary pressures, systematically capitalized by the real estate market for residential, commercial, managerial, or tertiary functions with extremely high profitability per square meter. Allocating large free horizontal surfaces to warehouses, inert depots, or static storage centers for recovered building components proves economically unsustainable for private actors and urbanistically complex for local administrations, resulting in a total absence of public or private physical infrastructures capable of absorbing and regulating the supply of circular resources.

The logistical-related reconfiguration of the territory must therefore be based on the **dematerialization of depots through Just-in-Time electronic platforms**. To overcome temporal asynchrony without saturating the physical and costly space of dense cities, storage must transition from a purely material and spatial dimension to a purely informational and predictive logic. By synchronizing supply and demand through advanced territorial marketplaces, directly interconnected and integrated with municipalities' digital registers of building and demolition permits, materials can be mapped, exchanged, and sold virtually when they are still structurally in place in the "donor" building, minimizing intermediate steps and transport transshipments.

This advanced approach requires an institutional and bureaucratic evolution of traditional land-use governance systems. The databases of municipal administrations and local authorities, historically dedicated to the mere bureaucratic management of building permits, must integrate using algorithmic platforms for georeferenced

tracking of energy-material flows. The moment an owner or developer presents an application for demolition or deep building renovation, the building must be mandatorily subjected to a digital census of available materials (pre-demolition audit). The platform places these resources within a virtual market months in advance of the actual physical opening of the construction site. A designer or contractor operating in the same territorial basin can thus view and option necessary components in advance, planning extraction so that the deconstruction of the donor building coincides millimetrically with the dry-assembly phase of the recipient building. In this manner, the building component moves only once in its transition cycle, moving directly from one structure to another and completely zeroing out the financial, spatial, and management costs of intermediate ground warehousing.

Where physical storage is still a technically indispensable step, urban development must provide for the structural planning of Proximity Metabolic Hubs strategically positioned in urban fringes; light, short-range logistics centers (calibrated to a maximum distance of 30-50 km) entirely dedicated to cleaning, conditioning, recertification, and the immediate introduction of material into the local circuit, rigorously protecting the global energy balance of transport. Structural urban planning on a broad scale, through master plans, territorial governance plans, and ecological zoning variants, must identify strategic fringe or margin areas, such as decommissioned railway nodes, former industrial freight yards, or marginalized and abandoned productive zones, to be converted into public service infrastructures for the urban circular economy.

These territorial hubs must not be assimilated conceptually or normatively to landfills, scrap yards, or passive and undifferentiated separate collection centers, but must be conceived and designed as true flexible urban factories, with high technological intensity and zero impact. Within the Metabolic Hubs, raw building components extracted from the deconstruction of the dense city undergo light industrial processing with low thermodynamic impact: the controlled mechanical removal of adhesives, foams, and cement mortars, dimensional reconditioning and geometric rectification, ecological protective surface treatment, and, above all, the execution of non-destructive diagnostic tests necessary for the official issuance of residual performance certifications. The sphere of action strictly circumscribed within the 30-50 kilometer threshold guarantees that the energy spent on handling and return logistics of materials remains well below the energy and carbon savings threshold guaranteed by upcycling practices, finally integrating matter management within the overall ecological, climatic, and spatial planning policies of the metropolitan territory.

D. Installation and the new life cycle

The final phase of the value chain, installation on the new construction site, does not simply constitute the concluding act of a constructive process, but represents the solemn moment of closing the circle and, simultaneously, the incipit of a new structural biography. However, the installation of recovered elements cannot be assimilated to the mechanical assembly of standardized industrial components; it requires specific **design and operational sensitivity**, oriented toward managing tolerance, adaptability, and the intrinsic heterogeneity of historical pieces, which carry the marks of their previous use.

The crucial node of this phase lies in the **design of joints and adaptive connections.** Since recovered components, even when regenerated, may present slight dimensional discrepancies, millimetric differences in sections, or minimal torsions accumulated in previous lives, fastening systems must be conceived as intelligent interfaces.

From a digital and managerial perspective, installation marks the definitive transition from the theoretical model to the as-built BIM. Each component is mapped in its final spatial position, and its unique identifier (QR or RFID) is connected to live data flows. At this precise instant, the Material Passport evolves into the Digital Twin. Installing strain sensors, accelerometers, or acoustic sensors during assembly allows for recording the “zero state” of the structure. This integration guarantees that installation is not seen as the final act of consumption, but as the insertion of the material into a predictive maintenance system that will guarantee its durability over time and, above all, preserve its performance characteristics for a future, further cycle of reuse.

From a critical standpoint, it must be emphasized that the installation of recovered materials radically shifts the center of gravity of value from the “product” to the “process.” In traditional construction, value is concentrated in new material that begins to degrade from the moment of its installation; in circular architecture, value resides in the **capacity for custody and life-cycle management**. The construction site thus becomes the arena where industrial history (crystallized in recovered matter) and technological innovation (expressed by monitoring systems and algorithmic management) converge into an unprecedented synthesis.

A further in-depth analysis concerns construction site responsibility and the role of the Site Manager. The installation of regenerated components requires constant verification of interface conditions: every bolting must be checked with calibrated torque wrenches, and every on-site weld must undergo immediate magnetic particle testing. The new life of the element depends on the quality of these connections. Ultimately, the success of the installation determines the credibility of the entire upcycling paradigm. When a steel beam, which has already served heavy industry for fifty years, is successfully bolted into a new residential complex or multi-purpose center, it is empirically demonstrated that reversibility is possible and that obsolescence is not an inescapable destiny.

This approach not only reduces instantaneous environmental impact, but also guarantees durable urban resilience, allowing the city to evolve like a living organism that constantly reassembles its constructive atoms without producing waste, while continuously regenerating its historical plus structural value.

DRY JOINTS

The closing of the logical, methodological, and operational circle of Material-led Design is by no means exhausted in the act, however complex and pioneering, of tracking, diagnosing, mapping, and regenerating a building component originating from the consolidated urban mine. The ecological effectiveness, global energy balance, and thermodynamic sustainability of this com-

plex reverse value chain risk being totally nullified at the most critical and delicate moment of the entire process: the phase of physical reinstallation and placement within the new architectural organism. To avert this drift and give full meaning to authentic circular economy in architecture, the operational practice of Upcycling Architecture must impose a radical, binding, and irrevocable paradigm shift: the absolute obligation to design installation and assembly nodes exclusively through mechanical, disconnectable, and rigorously **dry joints**. Instruments such as precision metric-pitch screws, adjustable structural bolts, male-female geometric interlocking systems, extruded metal support brackets, bayonet coupling profiles, harmonic steel elastic clips, and pressure joints must integrally and permanently replace chemical binders and wet pours in situ.

This approach does not represent a simple technological option among many, but rather a methodological imperative that alters the deep essence of the constructive detail and the joint detail. Designing dry means conceiving the node not as a permanent and eternal chemical welding point, but as a transition interface programmed to be explored, maintained, repaired, and ultimately disassembled without causing physical trauma to adjacent components.

This systematic transition toward the reversible mechanical joint dismantles the static and monolithic conception of the traditional construction site, converting it into an assembly, disassembly, and configuration platform with ultra-high geometrical accuracy. From a technical and systemic perspective, the adoption of dry joints guarantees three fundamental advantages that guarantee the project's sustainability in the long term:

• Absolute preservation of physical integrity and residual use value:
Purely mechanical disassembly excludes the application of destructive forces (such as violent percussions, chiseling, high-frequency vibrations, or uncontrolled thermal cuts) on the component during future phases of decommissioning or extraordinary maintenance. The external surfaces, geometric tolerances, and internal mechanical properties of the artifact are thus preserved intact, protecting its residual economic value for subsequent reuse.

• Selective separability of material flows and purity of fractions:
The total absence of surface contamination from cementitious glues or polymeric resins makes certain that every single layer of the construction package maintains its original chemical-physical purity. At the moment of the building's decommissioning, the thermal insulation, finishing cladding, metal substructure, and structural support can be separated instantaneously and directed to dedicated recycling or upcycling flows, eliminating the need for expensive and complicated industrial purification processes for contaminated materials.

• Spatial flexibility and millimetric repairability over time:
The intrinsic reversibility of the mechanical joint allows the targeted replacement or repair of a single deteriorated, obsolete, or damaged component without having to demolish, affect, or weaken surrounding construction elements. The building thus acquires a dynamic adaptive capacity, capable of being configured, expanded, or reduced based on changing human needs.

Imposing dry installation as a mandatory design and construction standard means programming the tectonic memory of the building organism from its very earliest ideational phase. The dry joint becomes an intelligent connection device that guarantees secondary resources a fluid, safe, documented, and energy-trauma-free transition through infinite and successive life cycles, definitively transforming architecture from a consumer of resources to a dynamic bank of materials constantly accessible for future generations.

		CONCRETE ACTION	ACTORS INVOLVED	STAKEHOLDER	INPUT/RESOURCES	DOCUMENTATION	PERMITS	OUTPUT	DECISION GATE	TIMING	LOCATION
PHASE A Urban Mining & Strategic Sourcing	A1	**Mapping of the territory and identification of potentially available buildings**	· architect · municipality · owner	· Material Bank · Local Authorities · Territorial Agencies	· GIS/cadastre · Building database · Urban plans	· Territorial framework · Building data sheet · Material flow map	· access to public data	· Long list of candidate buildings · Flow map	YES → A2 NO → Review criteria	1-2 weeks	office
	A2	**Site inspection and preliminary evaluation**	· architect · surveyor technician	· owner · facility manager	· inspection checklist · survey tools	· Site inspection report · Topographical surveys · Technical notes	· Building access · Ownership consent	· preliminary building sheet	YES → A3 NO → reject	1-2 weeks	on site
	A3	**Inventory and evaluation of existing materials**	· architect · engineer · materials expert	· Testing laboratory · Materials bank	· technical manuals · measuring instruments · samples	· Materials inventory · Technical data sheets · Qualitative assessment	· sampling · authorizations · testing	· material inventory · material passport · preliminary	YES → A4 NO → Further tests	2-4 weeks	on site/ laboratory
	A4	**Technical Verification and Compliance**	· Teacher · Certified laboratory	· regulatory bodies · certifying bodies	· technical regulations · reference standards	· test reports · certifications · safety data sheets	· Laboratory authorizations	· conformity reports · validated material passport	YES' → B1 NO → return to A2	2-3 weeks	laboratory
	A5	**Planning disassembly and logistics**	· Architect · Demolition company · Project manager	· conveyors · storage facilities	· building plans · schedule · construction site layout	· dismantling plan · floor plans · logistics plan	· Demolition permit · Safety plan	· dismantling plan · logistics plan	YES → B1 NO → Review	1-2 weeks	office / worksite
PHASE B Decon-struction & Recovery	B1	**Construction site setup and safety**	· Company · RSPP · Construction Management	· workers · Municipality	· PSC · Construction site layout · PPE	· Safety plan · Meeting minutes · Construction site layout	· preliminary notification · construction site permits	· construction site operating safely	YES → B2 NO → Adjustments	1 week	cantiere
	B2	**Selective disassembly**	· demolition company · specialized technicians	· Construction management · Materials expert	· Equipment · Dismantling manual	· Materials data sheets · Surveys during construction	·Environmental permits (if required)	· Recovered materials · Lot traceability	YES → B3 NO → corrective actions	2-6 weeks	cantiere
	B3	**Storage, labeling and traceability**	· logistics · material bank	· warehouse · insurance	· Storage spaces · QR labels · Software	· Lot sheet · Photo of materials · Handling	· storage regulations	· Stored materials · Updated database	YES → B4 NO → Adjustments	1-2 weeks	warehouse
	B4	**Transport and Delivery**	· transporter · logistics	· receiving company	· vehicles · packaging · routes	· DDT · GPS tracking · Insurance	· transport authorizations	· Delivered materials · Transport documents	YES → C1 NO → Review	1-2 weeks	on the road/ worksite
PHASE C Design & Integration	C1	**Adaptive Design**	· architect · engineer · designer	· Clients · Consultants	· Material inventory · Technical standards · BIM software	· project concept · technical reports · simulations	· Regulatory verification · Clearance (if applicable)	· preliminary design · selection of upcycled materials	YES → C2 NO → re-design	2-4 weeks	office
	C2	**Design detail**	· architect · engineer · materials technician	· Contracting company · Specialized consultants	· BIM · Material data sheets · Catalogs	· working drawings · construction details · cost estimate	· technical approvals	· executive project · bill of materials	YES → C3 NO → Review	3-6 weeks	office
	C3	**Technical validation and testing**	· laboratories · researchers	· universities · regulatory bodies	· samples · prototypes · instrumentation	· Test reports · Certifications · LCA assessments	· test authorizations	· Technical validation · LCA / EPD	YES → C4 NO → Changes	2-4 weeks	laboratory
	C4	**Project Approval**	· construction management · client	· competent bodies	· executive project · reports	· complete documentation · declarations	· building permit	· Approved project · Authorizations	YES → D1 NO → Additions	2-4 weeks	office
PHASE D Construction & Monitoring	D1	**Construction site preparation**	· Company · Construction Management · RSPP	· Suppliers · Municipality	· Layout · Materials · Schedule	· executive plan · safety plan · verbal	· construction site authorizations	· operational construction site	YES → D2 NO → Adjustments	1 week	worksite
	D2	**Construction with upcycled materials**	· Contractor · Construction site technicians	· Construction management · Suppliers	· Upcycled materials · Equipment	· Daily DI · Installation sheets · Photos in progress	· checks during construction	· completed works · traceability	YES → D3 NO → Corrections	2-4 weeks	worksite
	D3	**Quality Control and Compliance**	· Construction management · Test driver	· laboratories · certifying body	· Upcycled materials · Equipment	· inspection report · certifications · testing	· final certifications	· compliant building · certifications	YES' → D4 NO → interventions	2-4 weeks	worksite
	D4	**Monitoring and feedback**	· Building Manager · Research Team	· users · research institutions	· monitoring systems · usage data	· User Feedback Performance Reports · Life Cycle Assessments	· privacy (data)	· Final report · Future directions	YES → Continuously improving cycle	continuous (1-3 years)	on site

Fig. 82_The operating protocol. Source: *personal processing*

5.3. Digital traceability

The systemic integration of cutting-edge digital technologies represents the sine qua non condition for achieving the scale shift necessary to transform structural upcycling from an artisanal practice into a mature, scalable, and, above all, legally certifiable industrial process. Digital traceability tools evolve into true legal, technical, and performance guarantors of the reused component.

Investigating the role of technology means understanding how digitization allows for the objectification of used matter, endowing it with an unassailable and transparent technical identity. Traceability thus becomes the tool to dismantle the prejudice regarding the delicacy or unreliability of the existing.

Without a solid and interoperable digital infrastructure, capable of managing material flows in real time and interfacing fluidly with modern structural calculation software, Urban Mining would remain confined to niche interventions, incapable of truly impacting the carbon balance of the construction sector. Conversely, the coordinated adoption of tools such as BIM (Building Information Modeling), digital Material Passports, and notarization technologies like Blockchain allows us to imagine the city as a dynamic warehouse of parts and components, in which every structural element is cataloged, monitored, and ready to be reinserted into a potentially infinite life cycle.



Fig. 83_ The Brummen Town Hall , RAU Architects - Paesi Bassi, 2013. Fonte: *rau.eu - Petra Appelhof*

BIM as an information ecosystem for reuse

In traditional design, oriented toward the market for new materials, Building Information Modeling (BIM) gathers information on virgin components whose performance is guaranteed a priori by standardized industrial technical data sheets. From the perspective of structural upcycling, however, the digital model must be reconfigured to host, structure, and make queryable the immense mass of heterogeneous data deriving from the phases of Urban Mining, laser scanning, and diagnostic investigation of the existing structure.

Each digital object within the model is enriched with a series of specific parameters and custom data fields that describe its complete technical biography. We are no longer talking exclusively about nominal dimensions or theoretical strength classes, but about a deep informational stratification that includes:

- the exact provenance (the donor building);
- the years of effective structural service;
- microclimatic exposure conditions to atmospheric agents;
- the documented chronological history of maintenance or reinforcement interventions undergone.

This depth of data transforms the physical component into an intelligent object capable of communicating its residual health status and mechanical heritage to the designer.

This advanced information management represents the only concrete solution to overcome the informational asymmetry between the supply and demand of recovered materials. Through the use of open and interoperable standards such as IFC (Industry Foundation Classes), BIM makes it possible to create and feed libraries of "as-built" objects that reflect, with meticulous accuracy, the **actual availability of the urban deposit at a given moment**. The digital model thus becomes a space for negotiation plus simulation, where the architect no longer designs in an ideal void but composes space by testing different structural configurations based on the real mechanical properties (detected through non-destructive testing and laboratory analyses) of the components actually cataloged and available in the recovery warehouse.

Investigating the role of BIM in reuse also means considering its **capacity for integration with environmental databases for immediate monitoring of project impact.** Through LCA (Life Cycle Assessment) analysis integrated into the model, the designer can instantly visualize the savings in embodied energy and the drastic reduction in CO_2 emissions achieved by preferring a recovered component over a factory-new one. The digital model thus transforms into a dynamic vitality balance, where architectural quality and structural stability merge with the measurable efficiency of the resource.

In this way, BIM guarantees **total and multidimensional traceability**: from the urban mine to the new construction site, every structural element remains inextricably linked to its digital identity (the component's so-called Digital Twin). This informational continuity guarantees that critical information on safety, material fatigue, and sustainability isn't lost during the complex handovers of the supply chain (demolisher, transporter, regenerator, constructor), providing the final inspector and competent authorities with a certain, transparent, and unalterable documentary basis.

Material Passport

The Material Passport constitutes the individual, inalienable, and unalterable identity document of every single piece. In the context of structural upcycling, this tool must not be understood as a simple static technical data sheet, but as a set of dynamic and structured data that accompanies the component throughout its entire biological and technical existence: from its first installation in the last century to today's selective deconstruction, up to its new functional life in a different architectural organism. Its main role is to guarantee **radical transparency**, an essential element for enabling recertification and overcoming the bureaucratic and psychological barriers that currently hinder large-scale reuse.

A truly effective material passport must be structured upon extremely dense informational pillars:

- Geometric data and precise chemical characterization:
The passport must record tolerances actually detected in the field via millimetric laser scans, highlighting any plastic deformations or torsions accumulated over the years. Chemical characterization of alloys is fundamental. Knowing the exact percentage of carbon, manganese, or phosphorus in a historical steel is the only scientific protocol for rigorously evaluating its weldability and accordance with modern electrodes and joining processes.

- Performance and diagnostic data, and state of conservation:
Here, the results of non-destructive testing (NDT) performed on the piece are archived: ultrasonic tests to detect internal cracks invisible to the naked eye, magnetic particle testing for surface defects, thickness measurement to evaluate section loss due to corrosion, and, where possible, the measurement of residual stresses. These data allow for the scientific determination of the residual load-bearing capacity.

- Disassembly, reversibility, and maintenance instructions:
The material passport must possess a future projection. It must contain detailed technical notes and graphic diagrams on how the element was originally connected and, above all, on how it must be handled and maintained in its new context to guarantee its future, further deconstruction without damage.

The strategic and political objective of the material passport is the systematic dismantling of the risk of the unknown—namely that technical, regulatory, and insurance prejudice weighing on second-hand materials, which are often a priori perceived as less safe, less performant, or less noble compared to factory-new ones. By providing certain documentation, traceable through physical tagging systems (such as QR codes or RFID tags applied to the beam) and digitally notarized, an ontological and legal transformation of the material is enacted: it ceases to be considered waste pursuant to the Consolidated Environmental Act, to formally and substantially acquire the status of a construction product with declared performances.

This documentary transition facilitates the assumption of responsibility by designers, who can finally sign off on structural load tests relying on objective bases; it allows insurance companies to quantify risk and premiums based on real parameters; and, last but not least, it enables investors and clients to recognize in recovered material an asset of tangible economic value.

Ultimately, the Material Passport is the certificate that confers industrial and poetic dignity upon waste, making the circular economy a practice that is not only ethically necessary for protecting the planet, but technically rigorous, legally unassailable, and commercially competitive within the global market of sustainable architecture.

Digital Twins

The most technically sophisticated evolution of traceability applied to structural upcycling is represented by the Digital Twin. This technology establishes an unbreakable informational bond between the concrete construction element and its digital alter ego by **embedding IoT (Internet of Things) sensors** or advanced tagging systems. The physical application of laser-etched QR codes, RFID (Radio-Frequency Identification) tags, or NFC (Near Field Communication) sensors embedded directly into structural components (such as recovered steel beams or reinforced concrete columns extracted from industrial sites) makes it possible to query the matter at any time during its useful life, obtaining certain answers regarding its state of health.

This interdependent connection guarantees authentically “cradle-to-cradle” traceability, solving one of the most thorny and limiting problems of reuse: data dispersion during logistical transition phases.

During selective dismantling, transport, and above all, prolonged storage in intermediate warehouses, recovered material runs the paradoxical risk of losing its technical memory. Without a certain and univocal digital bond, a certified beam can be confused with an untested one, inevitably leading to the precautionary downgrading of both to anonymous waste for lack of evidence. The Digital Twin acts here as an informational lifeline: a simple on-field scan is enough to instantly retrieve the entire diagnostic history, weldability certificates, and toughness tests from the cloud, making certain that the performance identity stays anchored to the physical piece regardless of the numerous handovers in the supply chain.

Embedding the Digital Twin also radically transforms the operational phase within the new architectural organism. Once the recovered resource is reintegrated into a new structure, the **continuous monitoring system** makes it possible to observe its mechanical reaction under real load, eliminating uncertainties related to the material’s age. The installation of **strain sensors** (strain gauges), accelerometers, or acoustic sensors allows for sending constant streams of data to the virtual model. Using predictive analysis algorithms, the architect and engineer can perform **Structural Health Monitoring (SHM)**, early detecting anomalies, accelerated corrosive phenomena, or unexpected settlements that could derive from micro-defects inherited from the component’s previous life. The Digital Twin becomes an early diagnosis tool, elevating the safety standard of buildings constructed with recovered materials and making them, paradoxically, more monitored than those built with virgin materials lacking active monitoring.

From the perspective of infinite urban regeneration, management via Digital Twin ultimately possesses a prophetic and long-term value. The system archives cumulative stress to facilitate a future third or fourth cycle of reuse. Knowing with accurate precision how much mechanical fatigue a beam has undergone during its decades of second life will allow future designers to plan its subsequent relocation without having to resort to new, costly, and often invasive destructive testing cycles.

Ultimately, the Digital Twin makes matter speak, transforming the architectural skeleton of a complex city into a living and interconnected database. Digital technology thus becomes the solution against obsolescence and waste, making it possible to manage the built heritage as a continuous flow of intelligent resources, ready to be disassembled, revalidated, and reassembled in a perpetual cycle of environmental and structural value creation.

Blockchain and chain of custody validation

To guarantee the absolute integrity, unalterability, and radical transparency of the data contained in material passports, Blockchain technology provides technically indispensable prospects for creating an industrial-scale structural reuse market.

In an upcycling process, trust in the resource is the most precious asset and, at the same time, the most fragile: if information regarding a beam’s resilience, its chemical composition, or accumulated fatigue were lost, manipulated, or subject to transcription errors during the numerous handovers of the supply chain, the entire value of the component would instantly collapse, inevitably downgrading it from a noble product to uncertain waste.

The decentralized, cryptographically secure, and immutable nature of blockchain makes it possible to resolve this crucial problem at its root, establishing a certified “**Chain of Custody.**” Every time a structural component changes state, undergoes processing, or changes ownership (from the moment it is initially cataloged in the donor building during the Urban Mining phase, to its transfer to a regeneration center, up to logistical storage and final placement in the new construction site), the information transaction is recorded as a permanent block of data marked with a timestamp (timestamping). This distributed ledger is not under the control of a single interested entity, but is shared and validated by a network of actors (laboratories, engineers, companies), making any retroactive modification of performance data virtually impossible.

This capillary validation system reliably prevents the falsification of diagnostic data and ensures all actors involved (designers, construction companies, site managers, and above all, static load testers) that information relating to safety and material provenance has not been altered for commercial purposes or to conceal technical negligences. For a structural engineer called upon to sign off on the load testing of an architectural organism integrating steels recovered from a last-century Turin industrial site, Blockchain is the mathematical proof that the strength data upon which they based their calculation models are precisely those produced by the diagnostic laboratory months earlier, without any intermediate manipulation.

Furthermore, the implementation of blockchain enables the use of **Smart Contracts**, computer protocols that automatically execute transactions upon the occurrence of certain objective conditions. For example, payment for a supply of recovered HEA beams could be automatically unlocked by the system only when the analysis laboratory uploads the positive results of weldability or toughness tests to the ledger. This automation not merely accelerates financial flows and reduces the construction site’s bureaucratic timelines, but fundamentally eliminates possible legal disputes related to supply quality, making the reuse supply chain extremely efficient, dynamic, and attractive to major investors.

Technology thus becomes the trust bridge that enables a high-performance structural second-hand market, capable of competing with that of virgin materials not solely on the level of environmental ethics, but above all on that of disclosure and legal security. Making the choice of upcycling a rigorous, certified, and legally unassailable technical procedure through Blockchain means providing contemporary architecture with the required tools to convert urban deposits into mines of certain and documented value.

Ultimately, this system makes certain that the technical intelligence and embodied energy savings incorporated into the material remain an **undisputed public and private value**, protected by a digital infrastructure that prevents informational oblivion or negligence from compromising the strength and safety of the upcoming built environment.

5.4. The Regenerative Material Hub proposal

The systemic integration of advanced digital technologies represents the sine qua non condition for achieving the scale shift necessary to transform structural upcycling from an artisanal practice into a mature, scalable, and, above all, legally certifiable industrial process. Digital traceability tools evolve into true legal, technical, and performance guarantors of the reused component.

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Fig. 84_The Green Hall - Christiania, Copenhagen. Source: *makinglewes.org*

The proposal of the Regenerative Material Hub

The construction sector today stands at the center of a deep and continuing structural paradox, suspended between state-of-the-art geopolitical drives and operational resistances rooted in the real market. While on one hand the strategic framework of the European Union (guided by Green Deal directives, the milestones of the Circular Economy Action Plan, and the ambitions of the Renovation Wave) imposes an accelerated transition toward the absolute decarbonization of the anthropogenic stock and the hermetic closure of material cycles, on the other hand, the administrative and executive practice of the construction supply chain remains firmly anchored to linear extractive models or mere downcycling processes. This deep fracture generates a chronic system asynchrony, an epidemiological gap that separates high community visions from the actual bureaucratic, regulatory, and administrative reality characterizing the contemporary Italian construction site.

The inertia factors that freeze the disruptive potential of upcycling and prevent its real scalability on the market do not reside so much in a technological or data-driven deficit—areas in which the discipline has already reached peaks of absolute predictive sophistication—as they do in a rigid triple macro-structural barrier. The first obstacle is constituted by the informational fragmentation of the existing building stock, a condition that makes the procurement and flow of recovered materials intrinsically opaque, unstable, and unpredictable for institutional investors. This is compounded by a paralyzing regulatory and insurance impasse linked to the civil liability of control bodies, designers, and load testers, who are deprived of codified legal tools to determine and validate the residual mechanical performance of reused components. Finally, there is a widespread inadequacy of territorial logistical infrastructures, structurally incapable of welcoming and governing post-consumer waste through the lens of the resource, preferring the quick route of downgrading to waste.

To break this operational stasis and overcome the logic of the isolated academic prototype, transitioning toward a widespread and truly applicable macroeconomic model, this paper proposes the theoretical, methodological, and spatial structuring of the Regenerative Material Hub. This new entity is not conceived as a simple storage center or a passive warehouse of second-hand materials, but rather as a **hybrid infrastructure, simultaneously physical and digital**, specifically designed to act as a technical, legal, and aesthetic clearinghouse for building and industrial waste.

Optimized to respond to the very high settlement density, logistical complexity, and marked manufacturing vocation of the urban and industrial districts of Northern Italy, this integrated platform presents itself as the enabling systemic interlocutor. Its tactical objective is to guarantee, through a single territorial metabolic node, the ex-ante digital traceability of matter, the engineering safety of residual structural performance, and the formal dignity of the inherited component. In this way, the hub encodes the operational and legal tools necessary to convert the theoretical principles of Material-led Design into a construction practice that is finally real, safe, competitive, and contractable by the entire public and private clientele.

The Hub's business model

To guarantee long-term financial sustainability, operational scalability, and economic independence from public subsidy fluctuations, the Regenerative Material Hub cannot be structured as a mere passive storage depot or as a commercial intermediary for second-hand construction waste. Such an approach, based on one-off spot transactions of low-value-added materials, would expose the infrastructure to the same slim margins and high volatility that characterize the traditional scrap and inert waste market. To raise itself as a true engine of a systemic ecological transition, the Hub must promote an avant-garde economic model, theorized by circular economy pioneers like architect Thomas Rau (Rau & Oberhuber, 2016) and structured upon the methodological pillars defined by the Ellen MacArthur Foundation: the servitization of matter through the **Product-as-a-Service (PaaS) paradigm.**

In this scenario of radical financial and legal innovation, the Hub begins to **commercialize exclusively performance-in-use and functional services over time.** Building materials and systems with high technological, structural, and architectural added value are not sold to real estate developers. Instead, they are granted for use through long-term leasing contracts or performance subscriptions.

The legal ownership of the assets remains firmly with Fizz or the platform's partner industrial manufacturers, who assume direct responsibility for preventive and predictive maintenance, performance effectiveness, and monitoring the health status of the components throughout the entire period of operation within the host building.
This approach radically transforms the very ontology of the contemporary building organism. The building converts, according to Thomas Rau's apt definition, into a "***temple of temporary material services***" (or a material bank / building as a material bank). Architecture becomes a dynamic, reversible, and traceable aggregation of noble resources that temporarily reside within a specific spatial configuration to satisfy a limited-time human and housing need, ready to be surgically disassembled and returned to the value chain as soon as that need ceases to exist or changes its nature.

The PaaS model managed by the Regenerative Material Hub resolves at its root the main market failures that currently hinder the circular economy in construction, acting upon three highly core financial, operational, and design levers:

· Internalization of end-of-life and alignment of industrial incentives:
In the classical linear model, the material manufacturer has no financial interest in what will happen to their product after sale. In the PaaS model, since the manufacturer or the Hub remains the owner of the asset and knows with certainty that they will have to take it back at the end of the use cycle, the entire industrial incentive shifts toward eco-compatible design (ecodesign). It becomes economically imperative to design for maximum durability, facilitated repairability, and total component dismantlability. End-of-life ceases to be an environmental liability externalized onto the community and transforms into an internal asset of the company: recovering an intact component, easily regenerable and ready for a second leasing cycle, represents a direct recovery of financial capital.

· Financial soundness and cash flow recurrence for the Hub:
By replacing one-off transactional sales with recurring revenue streams based on service fees, the Hub stabilizes its business model. These predictable and constant cash flows over time make it possible to absorb and finance the costly still essential operations of advanced diagnostics (non-destructive testing, ultrasound, load tests), performance recertification and CE marking, precision reverse logistics, and the digitalization of Material Passports. This ensures the economic sustainability of processes that, if tied to a single traditional recovery construction site, would prove economically prohibitive and out of the market.

· Reduction of supply risk for designers and predictive cataloging:
One of the major obstacles for architects intending to practice Material-led Design is the absence of a reliable market: recovered materials whose future availability is uncertain cannot be specified in a project. Via centralized control of the flow of mate-

rials in circulation, the Hub can constantly track where resources are located in the territory, when individual lease contracts will expire, and in what performance state they will return to the warehouse. That predictive monitoring allows for feeding a stable, dynamic, and reliable digital catalog. The Hub can guarantee architects the scheduled supply of lots of recertified components months or years in advance, synchronizing the supply generated by deconstructions with the demand expressed by new designs.

Through the activation of the Product-as-a-Service model, the Regenerative Material Hub definitively overcomes the romantic yet economically marginal and localized dimension. It configures itself as an avant-garde infrastructural, financial, and logistic institution, capable of governing cash flows, matter, and information on a metropolitan scale. Construction matter, freed from the twentieth-century concept of ownership and destructive wear, flows continuously and non-destructively between the Hub and the territory, transforming the built heritage into a perpetual repository of social, economic, energetic, and lithospheric value.

Proximity logistics

To guarantee the deep thermodynamic sustainability of upcycling practices, the Regenerative Material Hub is structured around the pivotal principle of centralized governance of energy-material flows within a strictly circumscribed territorial radius calibrated to a regional or sub-regional scale. Within the overall environmental balance of a building organism, calculated through accurate Life Cycle Assessment (LCA) protocols, the geographical distance separating the point of decommissioning and extraction of the resource from the place of its subsequent processing and reinstallation represents the fundamental critical variable, capable of decreeing the ecological success or the catastrophic failure of the entire circular operation.

If the handling of ultra-high mass-density components generates greenhouse gas emissions greater than the quantity of carbon dioxide saved by avoiding the extraction and chemical bonding of virgin raw materials, upcycling instantly loses its scientific and thermodynamic legitimacy. To avert this paradox, the RMH configures itself as a device of territorial and transportational acupuncture, a proximity node rooted in the district fabric that reduces road transport to an absolute minimum and optimizes flows through a rigorous, scientific functional subdivision of its spaces. The hub is internally articulated into two operational and complementary macro-areas, which reflect the historical metabolic distinction between the technical nutrients and biological nutrients.

The first of these specialized sections is the **Technical Metabolism Workshop,** an industrial space conceived for the management, reconditioning, recalibration, and aesthetic and performance upgrading of all those mineral, metallic, and synthetic components that characterize the skeleton and envelope of modern architecture, such as structural steel profiles, aluminum extrusions, decommissioned monoblock windows, and post-consumer complex glazed systems. This section of the hub operates according to the canons of a true clinic for advanced tectonic micro-sculpture and regeneration. Through the combination of cold and delicate processing technologies, prominent among which are computer numerical control (CNC) assisted cutting systems, millimetric drilling machines, geometric grinders, and stations for dry ecological sandblasting with recycled inert materials, the workshop has the capacity to modify the morphology, modularity, and dimension of the inherited component to make it immediately compatible with the tolerances and requirements of the new project layout.

By intervening on the material and component in the solid state and in the structural configuration in which it is extracted, the hub preserves intact the formal intelligence, latent mechanical performance, and original embodied energy already incorporated in the artifact, reducing the energy input necessary for its reconfiguration toward an infinitesimal fraction as opposed to traditional recycling and foundry methods.

The second macro-organic area of the infrastructure consists of the **Biological Metabolism Laboratory**, a section entirely focused on the interception, treatment, and valorization of organic, renewable, and biodegradable matter flows coming from the surrounding territory. This laboratory explores the material frontiers of Regenerative Design, applying rigorous transformation protocols with low chemical impact and minimal thermal input to convert plant waste into high-performance bioclimatic building resources with exceptional thermophysical, hygroscopic, and acoustic properties.

This designed cooperation between territorial biological waste and nearby manufacturing not only allows for the stable and permanent storage of biogenic carbon within building components, actively subtracting it from the atmosphere for the entire life cycle of the building, but consolidates a symbiotic, economic, and landscape link between the regeneration of the dense city and the productive capacity of the surrounding rural territory, defining a self-sufficient, resilient district ecosystem with a structurally negative carbon footprint.

The Upcycling Hub by Roncelli Studio

The award-winning project The Upcycling Hub, conceived in 2022 by the Roncelli studio under the signature of designers Alberto Roncelli and Nicole Vettore (Roncelli Studio, 2022), represents the fundamental operational and theoretical benchmark for the Regenerative Material Hub model, radically dismantling the traditional typology of the industrial logistics warehouse (historically isolated from the social structure and inaccessible) to transform it into a manifesto architecture that combines spatial design with a neighborhood-scale circular supply chain model in the city of Vienna, Austria.

This avant-garde vision has achieved widespread international recognition, winning first prize at the Ethical Architecture Award in 2023 and entering as a finalist at the prestigious Superscape Greenshift competition in 2022, bearing witness to its capacity to make circular economy processes visible, tangible, and desirable for the citizenry. The concept addresses the immediacy of creating new logistical spaces for the storage and regeneration of building components, but expands this purely functional role by transforming the hub into a social aggregator and an open local market, where residents can access areas dedicated to self-repair, small-scale manufacturing, and educational workshops.

The building itself reinterprets and actualizes the **historical memory of our grandparents' artisanal workshop**, a place of proximity firmly anchored in the social and financial fabric of the neighborhood, where nothing went to waste and every resource, artifact, or fragment of matter was locally repaired, readapted, or reused with a reduced, if not entirely eliminated, impact on the entire global logistics and transport chain. This dimension of care and material proximity is reflected in an architecture that becomes a physical, visual, and programmatic manifesto of its own purpose.
The external envelope and internal partitions are made entirely by assembling and layering recovered windows and fixtures from different eras, shapes, and sizes, salvaged from Viennese deconstruction and renovation sites. This transparent stratification not only defines a dynamic skin from a thermal and visual standpoint, capable of filtering natural light to create an iridescent play of reflections inside the laboratories, but also acts as a permeable diaphragm: it visually connects the internal activities of the production lab with the surrounding public space, transforming the operational processes of upcycling into a visible, transparent, and desirable urban performance for passersby, almost as if to eliminate every barrier between the production of ecological value and the daily life of the citizenry.

Inside this flexible volume, interior design follows the same logic of **waste resignification**: the furnishings, drawing tables, material storage racks, and operational stations of the carpentry and light joinery workshop are entirely self-constructed and shaped starting from structural offcuts, solid wood waste, industrial processing residues, or decommissioned structural timber elements. Every work surface, chair, or container module preserves and exhibits the memory and surface signs of its previous lives, ennobling them through non-invasive and ecological finishing processes.

Above this interior landscape, the entire structural skeleton is designed according to the most rigorous principles of **Design for Deconstruction** (progettazione per lo smontaggio). This system is conceived to be completely disassemblable and reversible, relying exclusively on mechanical dry connections and joints, bolting, and interlocking systems that exclude the use of chemical binders, mortars, or irreversible binders. Such a tectonic setup permits the entire building to be disassembled with extreme ease at the end of its useful life cycle, to then be partially or totally reconfigured, relocated to another neighborhood of the city of Vienna that needs a comparable ecological outpost, or absorbed by the earth and industrial supply chains without leaving a trace and without producing debris.

This construction approach based on reversibility as well as reuse at the building scale radically and sharply dismantles and contrasts the downgrading logics of traditional downcycling, an ecologically and thermodynamically passive process that today (in the linear construction industry) is limited almost exclusively to the mechanical and indiscriminate crushing of cement debris, bricks, or stone materials extracted from traditional demolitions for the sole purpose of producing low-added-value road aggregates or sub-base fills for highways, irreversibly dissipating the embodied energy and intrinsic formal value previously accumulated in the artifacts.

From a procedural and operational standpoint, the hub is fueled through a short and circular zero-kilometer logistics network, structured to intercept waste flows directly at the source, namely from local manufacturing sectors, carpentry shops, metalwork shops, and selective deconstruction and demolition sites distributed in the neighboring urban fabric. This proximity procurement drastically reduces the environmental impact linked to long-distance transport even before the material enters the processing cycle.

Once inside the laboratories, raw components (ranging from solid wood beams to structural metal profiles and stone slabs) undergo careful **surface remediation**. Using non-invasive techniques such as cryogenic sandblasting, ecological stripping, and controlled mechanical brushing, layers of dirt, residual chemical substances, old glues, and toxic paints accumulated over the years are removed. This delicate cleaning and rehabilitation process is calibrated with rigorous precision so as not to affect the resisting section of the piece, preserving intact the native microstructure, wood fibers, and molecular composition of the inherited metal.
Subsequently, the no longer contaminated **matter is geometrically resignified in the solid state**, operating exclusively via high-precision Computer Numerical Control (CNC) technologies, millimetric millings, planings, and light workshop carpentry processes. This step deliberately avoids the conventional industrial processes of metal remelting, firing, or chemical-mechanical crushing of compounds, typical of standard recycling; such operations, in fact, require an enormous and unsustainable input of thermal and electrical energy. The hub instead intervenes by working the component in the physical state in which it is found, modifying its morphology, fixing points, slots, and joint systems to make it immediately compatible and integrable with the new and rigorous structural and performance requirements of the contemporary construction site.

This strict design practice, which fully adopts and codifies the principles of Material-led Design (material-guided design), completely overturns the contemporary paradigm of a priori conceptual and dimensional hyper-standardization. In traditional design, architectural drawing imposes a rigid, abstract, and immutable geometry, forcing matter to conform through the purchase of serial industrial catalog supplies and the production of enormous quantities of construction site offcuts.
The method promoted by Roncelli Studio inverts this logical flow: the project becomes plastic, flexible, inclusive, and adaptive, letting itself be guided and conformed by the intrinsic qualities, real dimensions, resisting sections, and geometries of the resources actually available in the urban mining deposit guarded by the hub. Geometric tolerance, the patina of time, formal heterogeneity, wood knots, and the marks of previous fixings on metals thus cease to be interpreted as defects to be corrected or concealed below layers of plasterboard cladding. On the contrary, these parts are elevated to generative vectors of the construction detail and expressive codes of a new tectonic honesty, in which every structural node recounts the historical path, and memory of the employed matter.
In this complex methodological structure, the Upcycling Hub achieves a radical spatial and functional evolution, synergistically merging three distinct souls into a single polyfunctional building organism: it operates simultaneously as a **factory, warehouse, and community center.**

As a **factory,** the hub is an advanced production and manufacturing center equipped with high-technology machinery, where raw matter is processed, engineered, and transformed into finished and certified construction components for the contemporary building market.

As a **warehouse**, the building constitutes a physical bank of second-hand materials and usage resources, an urban deposit structured to catalog, digitally map, and store structural elements ready to be re-introduced into the local economic cycle, offering Viennese designers and builders a constantly updated catalog of real resources.
Finally, and above all, the hub establishes itself as an energetic **community center**: an inclusive public space, free of physical and mental barriers, conceived to aggregate the neighborhood population. Here citizens are not passive consumers, yet actively participate in the life of the hub through educational self-repair labs (self-repair), circular economy dissemination courses, practical self-construction workshops, and meeting spaces where the processes of ecological regeneration are made visible, transparent, and desirable, increasing access to the spirit of sustainability.

From an ecological-thermodynamic standpoint, this integrated approach maximizes the conservation of the existing embodied energy (Embodied Carbon) already consolidated and stratified in the artifact at the moment of its first industrial production, avoiding climate-altering emissions deriving from the synthesis of ex-novo virgin materials. On a socio-economic level, the hub performs an extraordinary operation of financial resignification, converting what would legally, fiscally, and bureaucratically be considered a burdensome landfill disposal cost into a new economic asset with high local profitability.

This mechanism not only retains wealth on the territory, but stimulates the birth of **new highly specialized professional figures** in diagnostics and the processing of recovered matter. It thus structures a short, resilient, and autonomous supply chain, capable of protecting the neighborhood's building and artisanal market from geopolitical fluctuations, financial speculations, and energy price hikes that cyclically hit global supply chains.

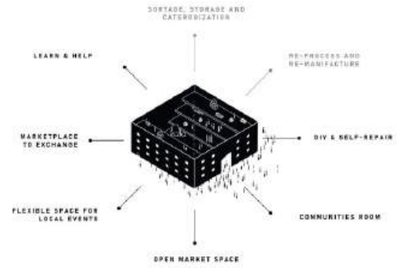




Fig. 85_ The Upcycling Hub, Roncelli Studio - Wien. Source: *roncelli-studio.com*





Fig. 86_ The Upcycling Hub, Roncelli Studio - Wien. Source: *roncelli-studio.com*

From Logistics to Community: Thoravej's Applied Vision 29

If the architecture and infrastructure of the hub offer the technical, economic, and logistical response to the crisis of material management, the ultimate meaning of this complex operational machine does not reside solely in the efficiency of flows, the accuracy of cataloging, or the reduction of storage costs. The genuine measure of change is identified in the habitable space and collective life that such processes manage to enable, and it finds its highest and most accomplished expression in avant-garde urban manifestos like Thoravej 29 in Copenhagen, the celebrated and radical intervention designed by the Pihlmann Architects studio (Pihlmann Architects, 2023).

At the root of the project for Thoravej 29 rests a profound and inescapable ethical and cultural urgency: to respond actively and transformatively to the present ecological crisis and the progressive commodification of urban space. In an era dominated by unregulated consumption and throwaway logic, the intervention opposes radical resource waste, establishing itself as a manifesto for an architecture that knows how to take a step back to make room for environmental accountability.

Conservation of Matter and Memory

The fundamental values of Thoravej 29 are nourished by the firm conviction that the conservation of matter inevitably coincides with the preservation of collective memory and the identity of places.

· Opposition to the tabula rasa:
The project firmly rejects the destructive approach of the tabula rasa, which erases the past to make way for speculative interventions detached from the context.

· Historical stratification:
Every building, every wall, and every surface carries with it the signs of time, the traces of use, and the accounts of those who lived in them. Destroying this heritage means erasing the very roots of the community.

· Architecture of continuity:
Preserving existing matter is a political and cultural act aimed at keeping intact the link among the past, present, and future of the neighborhood.

The Aesthetics of Time

Instead of hiding or smoothing over imperfections, the project valorizes the signs of time imprinted on the existing structures. The signs of wear, the layers of plaster, the traces of previous interventions are not considered defects to be corrected, but rather the aesthetic and material signature of the new space.

This approach overturns the traditional canons of building:

· Material authenticity:
Beauty does not reside within the polished perfection of the new, but in the sincerity of weathered materials.

· Visual identity:
The building's wrinkles become intrinsic ornamental elements, conferring a character that is unique, unrepeatable, and firmly anchored in the urban context.

· Spatial narrative:
Architectural space becomes a narrative instrument in which the history of the place continues to be told through its very material coherence.

This material vision immediately translates into a deeply social and community vocation, concretized in hosting the House of Food & People. This is a dynamic, inclusive, and transdisciplinary socio-cultural and working ecosystem, created to counter the isolation and gentrification of peripheral neighborhoods (Bispebjerg and Nørrebro). Within this regenerated former factory, collective kitchens, shared workspaces for creatives and professionals, artisanal workshops, food business incubators, and public areas open and permeable to the citizenry coexist. The architectural space is not imposed from above, but models itself organically around the needs of those who inhabit it, evolving over time thanks to the intrinsic flexibility of dry systems. Thoravej 29 thus embodies the paradigmatic response to the contradictions of the contemporary city, demonstrating that material circularity and community regeneration proceed along a single, inseparable track.

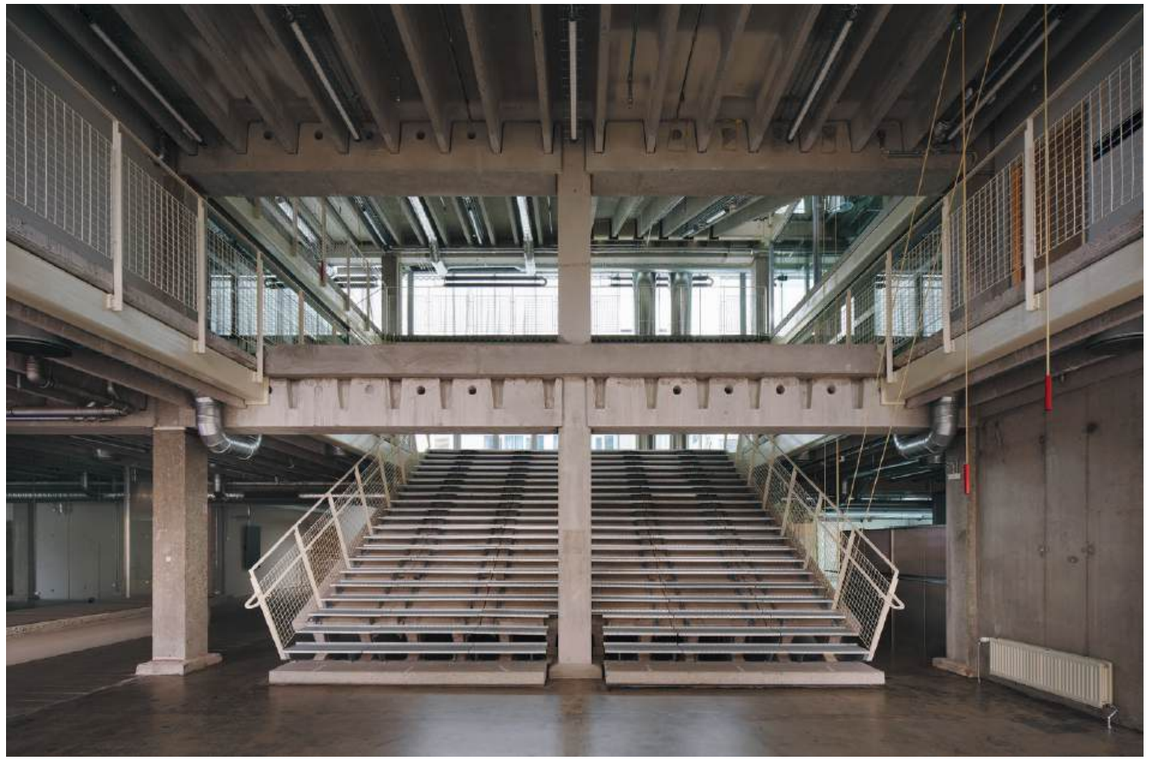


Fig. 87_Thoravej 29 - Pihlmann Architects, Copenhagen, 2025. Source: *thoravej29.dk - Hampus Berndtson, Samuel Causse*

CHAPTER SIX

06

Conclusions

The transition from the architecture of mitigation to that of Regenerative Design does not represent a simple stylistic option or an official update of compositional repertoires, but rather a structural necessity imposed by the planet's material finitude.

Within this evolutionary horizon, the research has shown how the systematic implementation of upcycling practices constitutes the main driver for overcoming the linear economic model and converting the building stock into an active metabolic organism.

The analysis of avant-garde international experiences and the comparison with the specificities of the Italian territorial context have highlighted that the main challenge for the sector does not lie in a lack of theoretical visions, but in the capacity to bridge the gap between pioneering innovation and common professional practice. To overcome the marginality to which upcycling has remained confined, the research defines three fundamental and operational development lines:

• The transition to Material-led Design and reversible construction site protocols:
Designing from the available resource rather than from the standardized industrial catalog requires rethinking the preliminary phases of the project. Establishing a rigorous operational construction site protocol (based on selective deconstruction and the use of dry mechanical connections) makes it possible to preserve the energy embedded in building components and avoids the heavy energy impacts typical of downcycling and aggregate crushing.

• Digital traceability and the valorization of secondary matter:
The uncertainty linked to the use of materials lacking traditional CE marking finds a concrete response in the establishment of advanced digital tools, including material passports and the creation of territorial Material Banks. The geolocation of waste streams coming both from construction and demolition activities and from external manufacturing supply chain scraps transforms matter from a bureaucratic liability into a certifiable, traceable resource capable of dialoguing with current performance and health-hygiene requirements.

• The proposal of the Regenerative Material Hub as a systemic infrastructure:
To stabilize and scale this model, the research envisions the configuration of dedicated logistic and civic hubs, understood as territorial hinges capable of connecting private client demand with the real availability of local recovery flows. These hubs do not simply fulfill storage and qualitative testing functions for components, but act as permanent laboratories for tectonic and aesthetic experimentation, capable of ennobling the patina and historical memory of waste.

From the organic articulation of these directives, it clearly emerges that upcycling architecture does not configure itself as a nostalgic exercise or an ephemeral installation, but rather as a solid, economically sustainable, and institutionally scalable construction practice.

Accepting a rigorous operational realism, waste ceases to be a regulatory constraint or a disposal cost and becomes the generative foundation of an ethical, durable building practice capable of generating measurable ecological and social value over time.

The evidence demonstrates that overcoming the extractive logic radically redefines the disciplinary and cultural profile of the designer: no longer a simple assembler of serial components derived from homogeneous industrial catalogs, but a true director of complex metabolic flows, able to interpret territorial specificities and becoming the custodian of the material memory embedded in artifacts. In this scenario, the compositional act coincides with the ability to negotiate architectural form with the unpredictability and singularity of the recovery resource, inaugurating a new aesthetics of secondary matter in which the trace of time and use do not represent imperfections to be concealed, but rather the tangible sign of a superior quality rooted in history and the conservation of planetary resources.

Nonetheless, Regenerative Design remains an enormously open, complex, and quickly evolving field, opening up future research scenarios of crucial importance for territorial governance and the transformation of the built environment. The trajectory of the coming years will require an intense, choral, and structured effort of multi-sectoral integration, intended to bridge that regulatory, methodological, and economic gap that still slows down and hinders the definitive transition toward development models on an urban and territorial scale.

First of all, from a legislative and legal standpoint, it will be indispensable and no longer avoidable to develop an ad hoc regulatory framework, drastically overcoming the current rigidity of certifications and codes of practice based solely on virgin industrial products. Such a reform must be capable of clearly disciplining technical qualification, long-term civil liability, and the legal traceability of reused components, redefining guarantee regimes and untangling the notion of building quality from traditional parameters of serial homogeneity.

On the techno-scientific and technological plane, the future of research must decisively focus on defining shared and universally recognized performance measures, integrating artificial intelligence and advanced BIM systems to predict and dynamically map waste streams in urban contexts, and implementing non-destructive testing protocols in the field. Such techniques and methods will be decisive in validating in real time, with absolute scientific strictness, the structural safety, thermo-hygrometric behavior, and physical durability of secondary matter.

Finally, from an economic, financial, and market perspective, the decisive challenge consists in the design and experimentation of new business models oriented toward deep circularity, such as the adoption of Product-as-a-Service (PaaS) logics applied to building components, the establishment of material capital financial passports, and the definition of structured tax incentives and targeted tax reliefs. These tools will be indispensable for amortizing and distributing the initial costs linked to pre-demolition audits, artisanal selective deconstruction, storage logistics, and recertification, making the circular economy not only ethically impeccable, but fully competitive and economically advantageous compared to the traditional virgin extraction market.

Only through this profound and rigorous continuous methodological, regulatory, technological, and experimental advancement will it be possible to ferry this vision from a phase of virtuous and isolated pioneering avant-garde to a structural, systemic, and widespread condition of contemporary living.

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La stesura di questo lavoro di tesi rappresenta il traguardo di un percorso di crescita intellettuale e personale, in cui la ricerca è stata guidata dalla necessità di esplorare nuovi temi e di dare forma concreta a idee nate nel corso degli anni di studio, con l'augurio che questo contributo possa servire da base per i ricercatori del futuro e per la costruzione di un'ecosistema migliore.

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Questo lavoro non rappresenta solo la fine di un ciclo di studi, ma il punto di partenza per una nuova fase della mia vita e della mia crescita professionale. Porto con me il rigore acquisito, la curiosità intellettuale e la capacità di osservare la realtà con uno sguardo profondo, consapevole che quanto appreso in questi mesi continuerà a guidare il mio modo di agire e di interpretare le sfide che verranno. L'augurio più grande è che questo elaborato possa fungere da punto di riferimento e da stimolo per i ricercatori del futuro, un piccolo ma significativo tassello capace di ispirare nuove idee e di contribuire attivamente, attraverso la ricerca e la dedizione, alla costruzione di un futuro migliore.

Letizia

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We are accustomed to considering our buildings as static monuments and our construction sites as enormous consumption machines, gears of a linear chain that extracts, uses, and ultimately discards without appeal. Yet every day, tons of precious matter are decommissioned, demolished, and forgotten, hastily reduced to simple disposal costs within an economic and production system that seems blind to its own exhaustion.

What if waste were not the end of a cycle at all, but the start of a new beauty that we stubbornly refuse to see?

"UPCYCLING the system" encapsulates a twofold, urgent objective. On the one hand, to dissect the upcycling system, analyzing its roots, mechanisms, and potential through theory and case studies; on the other hand, to make upcycling a system, transforming it using rigorous protocols from an episodic and niche practice into a common, replicable design method. This means stopping designing blindly, starting from industry catalogs and beginning to build from what already exists and inhabits urban space. Not simple recycling that consumes additional energy to destroy, fragment, and transform materials, but upcycling, a true art of building that preserves the authentic memory of matter, respects its identity, and improves its history rather than erasing it with the tabula rasa.

Through a deep and stratified investigation that combines a strict theoretical framework, the critical analysis of virtuous international case studies, and concrete experimentation grounded directly in the territory, this book demonstrates how waste can elevate itself to the generative engine of a solid, deeply reversible, and ethically rigorous architecture. Because the future of building can no longer be founded on the infinite extraction of new untouched resources, but must reside in the extraordinary capacity to take care, with intelligence and vision, of what we already hold in our hands.