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# Regeneration of the Built Environment from a Circular Economy Perspective

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# Research for Development

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Camilla Lenzi · Alessandra Zanelli  
Editors

# Regeneration of the Built Environment from a Circular Economy Perspective

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# Re-Using Waste as Secondary Raw Material to Enhance Performances of Concrete Components in Reducing Environmental Impacts



Andrea Tartaglia

**Abstract** This essay outlines the circular economy in the construction sector starting from the study entitled “Ethical concrete” in which techniques for the reuse of glass collection waste have been experimented to reduce the impacts of concrete products and improve their performances. In particular, the non-reusable waste derived by the separated collection of glass can find in the urban sector and in concrete production an interesting opportunity for application as a secondary raw material.

**Keywords** Secondary raw material · Foam glass · Environmental impacts · Production and waste management

## 1 Environmental Issues and the Building Sector

Over the last two decades, issues such as climate change, environmental degradation, sustainable use of the resources, economic development and urban resilience have become more and more strictly connected topics in global, European and national politics. On this subject are focused many development strategies, research funding programs, global and local initiatives. Many solutions find a convergence in the model of the so-called circular economy.<sup>1</sup> Moreover, a better use and reuse of resources, the reduction of emission during the productive processes and of the carbon footprint of products is fundamental to support the necessary transition to a climate-neutral

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<sup>1</sup>For the European Commission the circular economy is an economy in which “*the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, is an essential contribution to the EU’s efforts to develop a sustainable, low carbon, resource efficient and competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe*” (European Commission 2015).

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economy. In this sense, the role of the building sector and all the related industrial activities is fundamental to perceive this ambitious goal.

From the point of view of environmental impact and energy demand, many significant advancements have been made with regards to construction: especially, the new NZEB construction (nearly zero energy building) and passive houses are goals that, even if with significant design efforts and frequent financial issues, can already be obtained using products and solutions on the market. So, it is undeniable that nowadays the weakest phases in building processes are the construction and the end of life phases.

In this sense, there have also been numerous initiatives, including of a legislative nature, aimed at encouraging the reduction of consumption and impacts related to the construction of buildings. An example is the minimal environmental criteria (MEC)<sup>2</sup> which are compulsory in the public market and define the minimal environmental standards for design solutions, products and services throughout the life cycle, taking into account current market availability. For the construction activities, among many specific requests, there is a more general indication that at least 15% of the weight of all materials used for a building must be guaranteed to be recycled material.

In fact, waste management is a central issue in the proper use of resources. According to EU data construction activities alone produce almost 900 million tons of waste per year out of a total production (household rubbish, manufacturing wastes, etc.) in Europe of 3 billion tons every year (European Commission 2010).

Regarding household rubbish, the separate waste collection has certainly been an important improvement, but it still presents multiple critical issues with respect to the real recyclability of all the materials collected. For example, in Italy in 2017 glass collection produced non-reusable waste for about 250 kilo tons (VVAA 2018).

## 2 Scenario of the Research

This scenario and the studies developed by Enrico Bernardo (Materials Engineering Department of Università degli Studi di Padova) in the field of glass-based materials was the foundation on which the study entitled “Ethical concrete” was conceived with the aim of exploring the possibility of using waste products deriving from the differentiated collection of glass in the production processes of concrete products. The study was funded by a call for research and development by the Tuscany Region<sup>3</sup> to a group of three companies operating in the sectors involved (separate collection

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<sup>2</sup>The MEC (in Italian *Criteri Ambientali Minimi—CAM*) involve multiple activities and sectors in addition to construction, for example, electronic office equipment; interior furnishings; street furniture; social aspects in public procurement; incontinence aids; paper; printer cartridges; public lighting; cleaning and hygiene products; urban waste; collective catering and foodstuffs; sanitation for hospital facilities; energy services for buildings; textiles; vehicles; public green. The MEC are constantly updated and those related to building and design has been updated in 2017. The updated list and its contents are published on the Website of the competent Ministry.

<sup>3</sup>Bando Unico R&S 2012—Regione Toscana.

and treatment of waste and production of concrete products). In particular, the team included: Unibloc s.r.l. (operating in the sector of concrete vibro-compressed components, responsible for the research was arch. Riccardo Cecconi) as group leader and supported by Assobeton; S.A.M. Engineering S.p.A. (construction company also operating in the production of prefabricated concrete panels, responsible for the research was engineer Tiberio Pochini); La RevetVetri s.r.l. (operating in the separate collection of urban waste, responsible for the research was engineer Massimo Ravagnani); DiDA—Dipartimento di Architettura of Università degli Studi di Firenze (scientific partner, responsible for the research was Alessandro Ubertazzi with Benedetta Terenzi); ABC department—Architecture, Built environment and Construction Engineering of Politecnico di Milano (scientific partner, responsible for the research was Andrea Tartaglia).

The idea was to transform a waste normally disposed of in landfills into a “new” raw material. Moreover, the reuse for construction components had to be conceived by verifying its environmental compatibility, technical feasibility and economic sustainability.

The first step was therefore to identify how and in what to “transform” the waste from glass recycling. Thanks to the support from Enrico Bernardo and the alternative production processes designed by him, the use of the waste for the production of foam glass was identified as the best solution<sup>4</sup> (Table 1). This is a product already widely used in the construction sector in Northern Europe especially as an aggregate in concrete mixtures. The significant advantages related to the processes proposed by the “Ethical concrete” study are primarily:

- The use of waste and not of new resources and components saving the use of a huge amount of non-renewable resources;
- A production process that requires lower temperatures compared to the typical process that starts from new raw materials, this means a reduction in the quantity of energy involved in production;
- The normal presence of organic elements in the waste that allows the activation of the foaming process without the use of additives, with a further advantage over the use of resources.

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<sup>4</sup>To obtain this result “several alternatives have been tested for the waste glass processing in order to achieve an adequate glass sand that can undergo the necessary heat treatment to obtain foam glass. As a consequence of this effort, a virtuous circle has started with the ambitious goal of giving dignity to a new material from a waste product which currently is simply disposed of in dumps. A series of samples with slightly different physical–chemical characteristics have been produced with tests run by the researchers, according to the procedures used in the thermal process to obtain the material set by prof. Bernardo. By comparing the different properties of the foam glass samples obtained, the partners of this project have identified as the most interesting material, according to the set goals, the one with the best ratio between compressive strength and density, therefore, with the best specific resistance. This is because the aggregates are not particularly light but significantly resistant in comparison to the ones currently on the market (Terenzi 2013: 110–122). From the chemical perspective, it has been observed that the organic material, naturally present in the waste used, is alone enough to foam the glass without the help of additional agents which, otherwise, would have to be added to the mixture” (Tartaglia and Terenzi 2016).

**Table 1** Results of laboratory tests referred to the different alternatives considered for the foam process. The composition of the samples of glass waste was intentionally varied with different additives and subjected to diversified heat treatments in order to favour their optimal and homogeneous foaming

Sample		Apparent density	Compressive strength	Specific strength
Composition	Heat treatment	g/cm <sup>3</sup>	Mpa	(N mm)/g
Glass waste + 1.2% MnO <sub>2</sub> + 1.5% SS + H <sub>2</sub> O	850C 10 min	1.093	5.82	5324
Glass waste + 1.2% MnO <sub>2</sub> + 1.5% SS + H <sub>2</sub> O	875C 10 min	0.736	4.643	6306
Glass waste + 1.2% MnO <sub>2</sub> + 1.5% SS + H <sub>2</sub> O	900C 10 min	0.56	2.415	4313
Glass waste + 1% CaSO <sub>4</sub> + 3% SS + H <sub>2</sub> O	850C 30 min	0.506	1.524	3012
Glass waste + 1% CaSO <sub>4</sub> + 3% SS + H <sub>2</sub> O	900C 10 min	0.764	5.974	7816
Glass waste + 1.2% MnO <sub>2</sub> + 3% SS + 3% C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> + H <sub>2</sub> O	850C 10 min	0.74	4.751	6418
Glass waste + 1.2% MnO <sub>2</sub> + 3% SS + 1.5% C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> + H <sub>2</sub> O	875C 10 min	0.987	4.77	4830
Glass waste + 1.2% MnO <sub>2</sub> + 3% SS + 1.5% C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> + H <sub>2</sub> O	900C 10 min	0.848	4.007	4724
Glass waste + 1.2% MnO <sub>2</sub> + 3% SS + 1.5% C <sub>3</sub> H <sub>8</sub> O <sub>3</sub> + H <sub>2</sub> O	950C 10 min	0.862	5.084	5901
Glass waste + 1% C + 1.5% SS + H <sub>2</sub> O	900C 10 min	1.19	5.318	4461
Glass waste + 1% C + 1.5% SS + H <sub>2</sub> O	900C 10 min	1.14	5.294	4630

Source Enrico Bernardo—Università di Padova

In particular, the thermal sintering process for the production of expanded glass has proved to be the most suitable with respect to the objectives and also the most efficient both in terms of costs and impact.

### 3 Applications for Building Sector

The second step of the study was the application of this “new” second raw material in products for building construction and the verification of the performance of such components.

Foam glass is a material that finds large application as light aggregates for concrete products. Because the foam glass pieces that derive from waste had lower compressive strength values than those of the foam glass obtained from pure glass, the decision was made to test the usability in lightweight concrete components (lightweight vibro-compressed concrete blocks and prefabricated panels to be used for example as vertical partition elements or vertical closing elements in buildings for industrial, commercial use and other civil constructions) which normally do not require high structural performance.

The goal was to produce components able to guarantee the requested mechanical standard but with lower thermal conductivity and weight. For this reason, a careful regulatory analysis has been carried out in order to set the minimum required performance for blocks and panels which, subsequently, have been compared with the market demands and the performances offered by the elements normally on the market.

The prototypes of the blocks were realized in the production plant of Unibloc s.r.l. using an optimal geometry<sup>5</sup> that would allow both the construction of a lightweight concrete block with commonly used aggregates (e.g. expanded clay), and the use of the expanded glass obtained in the experimental phase from the glass dust coming from the waste.

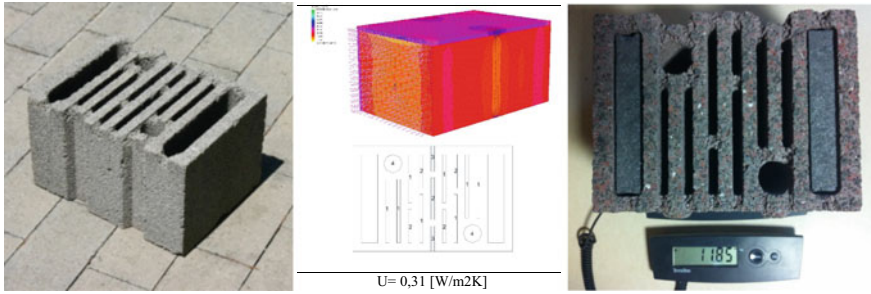
Instead, the prototypes of the panels were produced by the laboratories of S.A.M. Engineering S.p.A., equipped with a production control system (F.P.C.) certified by Bureau Veritas Italia for the production of elements with CE marking.

The prototypes, both the blocs and the panels, had aesthetic characteristics absolutely akin to the corresponding products of current productions but they showed significant differences in terms of performance.

In the case of blocks, following a refinement and sorting process of the geometries of the block and of the aggregates in foam glass from waste it was possible to obtain a reduction of the mass of about 25%, passing, with comparable performances, from a concrete lightened with expanded clay block with a mass net volume of 1000 kg/m<sup>2</sup>

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<sup>5</sup>For the definition of the optimal geometry and a comparison of the results obtained from the test geometries, the thermal values (conductivity) defined in the UNI EN 1745 standard were used; the cavities of the block were evaluated according to the procedure indicated in EN ISO 6946 and each cavity was considered as an average having its own thermal resistance, from which the conductivity in relation to the thickness was calculated.



**Fig. 1** Images of a prototype block realized by Unibloc s.r.l. with aggregates of foam glass from waste and verification of characteristics. *Source* Unibloc s.r.l.

to a concrete block lightened with foamed glass with a net density of  $750 \text{ kg/m}^2$ . A significant result, because one of the aims of the study was to not only work on the issue of sustainability of the products but also on their performances (Fig. 1). In this case, the analysis demonstrated that with light aggregates from recycled material it was possible to improve the thermal performance of concrete products with a significant parallel reduction in volume mass and without a drastic reduction in resistance.

In the case of prefabricated panels, the experimentation was carried out with two types that are part of the current production of the company, characterized by different total thickness and insulation but both made with class C32/40 concrete. The first type was made with two outer concrete layers (5 cm thickness each) and in the centre 10 cm of polystyrene as insulating material for a total thick of 20 cm thick. The second was differentiated by a greater thickness of the insulation (two polystyrene panels 5 + 9 cm interposed) which brought the total thickness to 24 cm.

In both cases, the two outer layers were joined together around the perimeter and internally with ribs or connectors.

The casting process was the same as traditional panels: preparation of the formworks to the required dimensions and treatment with disarming of the surfaces in contact with the concrete; installation of metal reinforcements, and spacers to ensure the correct iron cover and of special inserts (for the thermal cut and for lifting and moving the panels); concrete casting for the outer layer of the panel; spreading and the vibration of the first external layer; compacting of the castings; installation of polystyrene insulation for the thermal cutting layer and that for polystyrene intermediate lightening; completion of the reinforcement of the inner layer of the panels; final casting and levelling of the layer that would constitute the internal part of the panel.

The drying process was natural, and a difference was pointed out between the normally used concrete and that realized with foam glass. After twenty-four hours the first reached a characteristic resistance  $R_{ckj} 25 \text{ N/mm}^2$ , instead the second reached an average  $R_{ckj}$  of  $15\text{--}17 \text{ N/mm}^2$ . Instead, after 28 days, the results were in line with what was expected based on the mix design tests (Table 2). In particular, the breaking

**Table 2** Summary of the average resistances obtained and comparison with the concrete normally used in the production of panels by S.A.M. Engineering S.p.A

Aggregates	Weight cube 15 × 15 × 15	Concrete density (kg/m <sup>3</sup> )	Compressive strength at 24 h (kg/cm <sup>2</sup> )	Compressive strength at 7 days (kg/cm <sup>2</sup> )	Compressive strength at 28 days (kg/cm <sup>2</sup> )
Mixed	6.7	1985	165	265	385
Foam glass	5.85	1730	160	250	360

Source S.A.M. Engineering S.p.A.

strength of the element with aggregates deriving from the waste was slightly lower (5/6%) compared to traditional ones, but with a reduction in the total weight of the order of 12/14%.

## 4 Conclusions

Building products made with the new type of foam glass allows for the pursuit of new levels of sustainability. A sustainability that can be defined as “active”, as it adds value to glass waste without further treatment, with a consequent reduction in the carbon dioxide emissions of the final product. It also presents the same ease of recycling in the process of disposal (...) Moreover, there would also be a “passive” sustainability derived from the energy efficiency of buildings and the comfort of the environments resulting from the use of the expanded glass aggregates derived from recycling, as demonstrated by tests performed on prototypes during the “Ethical Concrete” study. (Tartaglia et al. 2016: 220)

Furthermore, from the first in-depth analyses about the realization of an industrial production process, it emerged that glass foam from waste could potentially have a final cost that is more than 20% lower than that of the material currently on the market derived from new non-recycled glass.

The process and product innovation—related to the possible reuse in the building sector of up to 250,000 tons per year of glass waste (currently to be land filled)—would reduce the use of non-renewable raw materials derived from quarry extraction (with the related environmental and landscape problems), would decrease energy consumption in production processes, would improve the performance of a number of products widely used in the construction sector (better energy performance and load reduction) with a consequent improvement in building performance, would diminish process and material/product costs and would create new production chains and new entrepreneurial opportunities.

In this sense, the “Ethical concrete” study highlights a significant opportunity for the realization of a true circular economy, through the transformation of an environmental criticality into an economic opportunity with significant correlated environmental benefits.



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