Superuse and upcycling *through* design: approaches and tools

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.

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Abstract. In Italy, first EU Country to have made Green Public Procurement (GPP) one hundred per cent mandatory, the recovery of construction and demolition (C&D) waste, the use of recycled materials and design for disassembly have been mandatory in public building projects since 2015. Nevertheless, in Italy, the renovation and substitution of existing buildings, not conceived to be easily deconstructed, generates 53 million tons/year of C&D waste (80% mixed inert waste) while the recovery rate is limited. Since 2012, the research team has been engaged on the increase of resource productivity in the building sector with two focuses. With the Atlante Inerti Project, co-funded by the EIT Climate-KIC, the team has experimented the upcycling of aggregates from the recovery of inert waste in prefab concrete design products for the building and outdoor furniture industries, testing innovative production techniques (large scale additive 3D printing). Simultaneously, the main research focus is the integration of adaptive reuse of buildings with superuse of components and materials: strategies inherent to the preservative Italian approach, complemental and preferable to recycling according to the EU Waste Hierarchy, still underestimated by the Italian legislation. The team has experimented the process of scouting construction/industrial waste materials at the local scale, with the application of the harvest map tool, to complex urban districts in Rome, in order to demonstrate how superuse and upcycling can represent reliable technical options widely replicable on a supply chain scale for increasing resource productivity in the building sector.

Keywords: superuse, upcycling, harvest map, recycled aggregates, design for disassembly, Italy.

1. Italian GPP policies as a first approach to Circular Economy in the built environment

In Italy, first EU Country to have made Green Public Procurement (GPP) one hundred per cent mandatory, the recovery of construction and demolition (C&D) waste, the use of recycled materials and design for disassembly have been mandatory in public building projects since 2015. In fact, the adoption of CAM (Minimum Environmental Criteria of the National Action Plan for GPP) for Buildings (DM 24/12/2015 and updated version DM 11/10/2017) has been made mandatory by the Italian Law 221/2015 and thereafter by the New Procurement Code (Legislative Decree 50/2016). These Criteria for interventions on public buildings, even though not systematically applied yet, establish a set of measures strictly related to the objective of Resource Efficiency, among a series of energy and eco-compatibility

targets. With reference to building materials and C&D waste, CAM for Buildings impose the following mandatory measures: use of a minimum recycled content of 15% in weight on the total weight of the materials used; design for disassembly applied to at least 50% in weight of the total number of buildings components used in the intervention; 70% diversion from landfill of generated C&D waste (in weight); pre-demolition audits; reuse of blocks in stone and mixed (stone and bricks) masonry for foundation and elevation works.

The mandatory recycled content is a rather limited target, which does not recognize the higher value obtainable from the valorisation of materials through reuse strategies. Anyway, though still partial, this form of promotion of Resource Efficiency in the construction sector is pushing companies to create synergies at the supply chain level. This approach is well represented by the EPR (Extendend Producer Responsibility) model for the building sector proposed by the Centro Materia Rinnovabile, a private research and communication institution collecting the main construction industry stakeholders. The project focuses on creating a "Collective Construction System" [1] by working on various normative instruments (such as End of Waste criteria, specific principles for the identification of by-products, etc.) which could help applying Circular Economy practices in the building sector. This project shows how, though the targets should be progressively raised, CAM for Buildings represent a turning point for Italy in the implementation of circular strategies to the built environment which, today, is still underestimated.

In fact, in Italy, the renovation and substitution of existing buildings, not conceived to be easily deconstructed, generates 53 million tons/year of C&D waste [2] of which almost 80% is mixed inert waste, while the recovery rate is still limited. Unfortunately, in Italy, the same quantification of C&D waste produced each year suffers a recognized uncertainty [3] due to a non-widespread data collection on the national territory, which leaves out small volumes and illegally managed waste. The correctly recycled aggregates (almost 70% based on some estimates) are mainly used in road works and environmental recoveries and, only to a very limited extent, in constructions (fillings, bases).

2. National experiences with reference to C&D waste superuse and upcycling

Since 2012, the research team (RT) has been engaged on the increase of resource productivity in the National building sector with two focuses. First of all, facing the main criticality (in terms of quantity) consisting in the failure to reintroduce inert waste in the building sector in the form of building materials or building products. Secondly, integrating the adaptive reuse of existing buildings (a widespread practice in the Country) with reuse of components and materials, a strategy inherent to the preservative Italian approach, complemental and preferable to recycling according to the EU Waste Hierarchy (EU Dir. 98/2008), but still underestimated by Italian legislation, as mentioned before. In particular, the RT is working on two complementary approaches: *superuse* – intended as «a design approach based on the search of discarded materials, whose usefulness has been wasted, aiming to identify their reuse potentialities and turn their features into an added value for new products and buildings» [4] and *upcycling*– intended as «the practice of recycling material in such a way that it maintains and/or accrues value over time (the opposite of downcycling)» [5]. The first strategy should be considered preferable from an environmental point of view, while the second should be applied in a residual way to non-reusable materials (as in the case of mixed inert waste), but still lot of work is needed in this direction.

In fact, despite early researches on these issues were conducted in Italy since the beginning of 2000 [6], if we look at reuse and superuse design and construction experiences in the building sector in the Country, these are generally still limited to small temporary buildings or to interior design projects. Only a few design teams are starting to systematically work with this approach on a large scale, while in other Countries these are becoming consolidated practices (for instance, in the Netherlands, with the work of Superuse Studios and in Denmark, with the work of Lendager Architkter).

One of the few Italian teams actively designing with waste materials is ARCò Architecture and Cooperation, a cooperative founded in 2012 by a group of architects and engineers dedicated to the production of sustainable architecture and landscape design. ARCò explores the local traditional techniques using different natural and recycled materials, in order to guarantee that the construction phase can be run independently by the communities involved, an approach which brought the

Cooperative into the world of international cooperation, where it uses its skills to face and solve the different issues of humanitarian emergency.

Among ARCò's works, the *Design and Build with Økm (local and recycled materials) Workshop* is worth to mention: the sixth one within a series of workshop co-founded by the EU Erasmus+ Project BIØN (Building Impact Zero Network), it was held in June 2018 at Casa Chiaravalle (in the southern part of Milan), a place confiscated from the organized crime that in the next future will become a reception centre for immigrants. The team enrolled students, migrants, NEET, unemployed, architect, engineers, coordinated by ARCò, in a four-week training and hands-on experience, leading to the realization of a 1:1 object inside the complex of Casa Chiaravalle (figure 1). Using the building techniques of Earthbags and Earthship, with natural and upcycled waste materials, the team created a physical and theoretical space for a discussion on the local sustainability exploring the potential of alternative and low cost building techniques. Mainly for the necessity of a responsible use of natural and unconventional resources, the project focused on the reuse of wooden window frames, bottles, Plexiglas panels, pallets, combined with Earthship and Earthbags, in the search for appropriate technologies with little processing or transporting and low environmental and economic costs.

Figure 1. The new pavilion at Casa Chiaravalle: construction phase (a), views of the façade with reclaimed windows and wooden frames (b,c). Photos, courtesy of A. Battistella (ARCò).

Furthermore, one relevant superuse experience recently conducted in Italy is the refurbishment of Villa Maggiore, in the northern lake district, by the architect Cèsare Peeren (Superuse Studios), a project involving the participation of the RT, that will be described in full details further down in paragraph 4, along with other recent experimentations led by the RT.

As far as the upcycling strategy is concerned, at present in Italy, recycling of pre-consumer waste is widely adopted in the industries producing building materials and components (for example, in the ceramic and wood industries), whereas C&D waste is generally down-cycled. The operators of the recycling sector report many difficulties in selling their certified recycled aggregates, while they receive

significant amount of inert waste. Thus the plants tend to get full due to the lack of a constant demand, because recycled aggregates are only used in low value, discontinuous applications. Therefore, Italy needs to face the significant challenge of reintroducing the aggregates deriving from the recycling of mixed inert C&D waste in the construction sector, through the strategy of upcycling.

3. Facing the main national challenge in the C&D waste management: upcycling inert waste

With the Atlante Inerti Project, co-funded by the EIT (European Institute of Innovation & Technology) Climate-KIC Accelerator Program 2016, the RT has experimented the upcycling of aggregates from the recovery of inert waste in prefab design products in architectural concrete for the building and outdoor furniture industries, testing innovative production techniques, such as large scale additive 3D printing, to activate local closed-loop production chains.

Atlante Inerti Project (AIP) is an information, research and development project (by architects P. Altamura, G. Chiummiento and M. Cutini) from which a business project derives, with the aim of promoting innovative uses of recycled aggregates. AIP has developed a geo-referenced map of certified aggregate suppliers in the national territory [7], drawing attention to the supply and encouraging the meeting with demand through networking activities between producers (recycling plants) and potential users (industries, construction companies). The platform is the first specific database in Italy and derives from a benchmarking activity highlighting the importance of information tools to identify qualified secondary materials producers and to encourage the use of reclaimed materials. Since 2016, AIP has undertaken design and prototyping activities on concrete products with the exclusive use of recycled aggregates, identifying the most suitable standard and innovative technologies for this unprecedented experimentation in Italy. These activities, resulted in two different applications, demonstrating the feasibility of using recycled sand for the production of prefabricated concrete products.

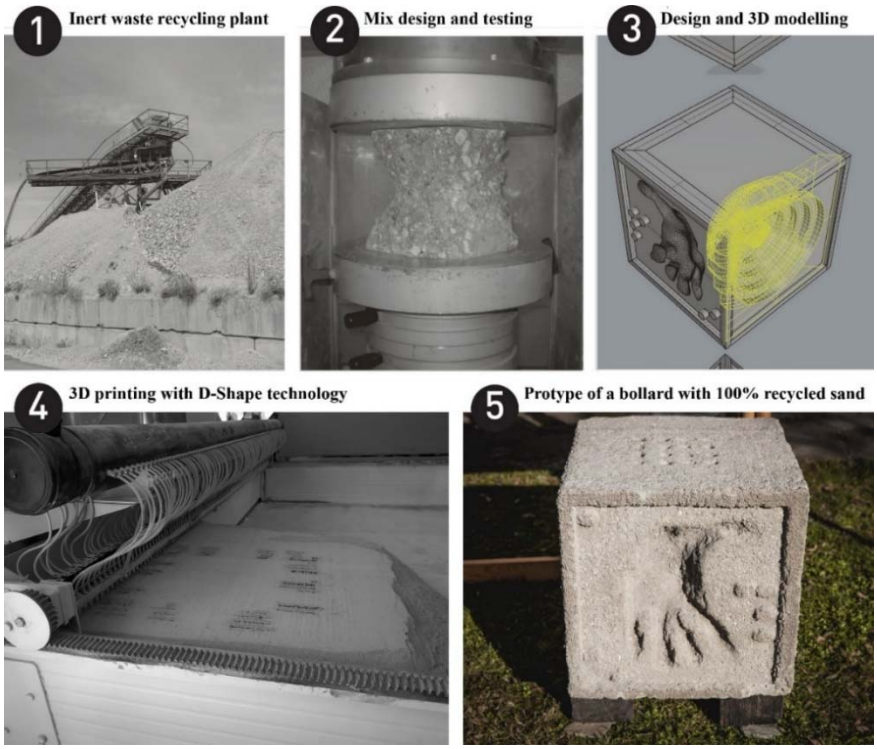

Figure 2. Phases of the upcycling process applied by AIP to inert waste.

The first one concerned the use of recycled aggregates in a large 3D additive printer, using sand and mineral binders to make monolithic concrete products. This technique, developed in Italy and covered by patent (D-Shape by Dinitech), generates complex forms, functional to the construction of building

components and urban furniture elements with high aesthetic value, giving added value to the SRM, with no waste in the production process and using a low embodied energy magnesium binder. After the experimentation phase with the printer, used for the first time by AIP with a recycled sand from C&D, a phase of characterization of the innovative concrete was carried out with experimental tests developed by the CertiMaC Laboratory in Faenza (ENEA, CNR). The aim was to evaluate and compare the mechanical resistance levels achievable with the printing technique applied to recycled aggregates with two different binders (cement and magnesium). The results of the tests showed that the magnesium binder, preferable from the environmental point of view, proved to be less efficient than cement in terms of mechanical properties (magnesium bonded concrete, compressive strength of 7 MPa; cement bonded concrete, 25 MPa). The second mix has a medium-high strength class (C20/25, NSC - Normal Strength Concrete) and can be used for different types of non-structural products. AIP then created a prototype (cubic with a side of 60 cm, with 6 extremely differentiated 3D-shaped faces, conceived as a bench or a bollard) (figure 2), specifically designed to test the technical and aesthetic performance of the recycled concrete, adopting the cement binder for its greater potential. The prototype represents a convincing result in terms of aesthetics and performance, though the printing process proved to be not completely satisfactory: the duration and costs of the production technique are still too high, due to some aspects not yet resolved in the equipment, entailing the need for supervision by specialized workers.

The second application, therefore, led AIP to develop a series of modular outdoor furniture pieces with conventional concrete vibro-compression techniques. These modules and their assemblies have been prototyped and are currently ready for industrialization (Project *Sistema-T Ricoeso*).

4. *Superuse* design approach: application of the harvest map tool in Italy

Simultaneously, the main focus of the RT's activities is the integration of adaptive reuse of existing buildings with superuse/reuse of components and materials: a preferable but more complex approach, compared to upcycling, as mentioned before. The RT is experimenting the process of *scouting* waste materials [8] at the local scale, not just from the building sector but also from other industries. With the aim of reducing the energy embodied in the materials used in any type of building intervention, of eliminating the consumptions and emissions for the production and transportation of "new" materials, as well as of activating small-scale circular economy processes, the design process should *start* with the scouting of materials. These include any wasted material, component, product suitable for use in architecture (by-products, defective products, dead stock, leftovers, processing waste, C&D waste, etc.) available in the area adjacent to the intervention site, within a limited distance - on average a radius of 25 km – which have to be inserted in a harvest map, becoming a precondition for the project. The systematization of this phase in the building process is aimed at the enhancement of local waste by design with actions of superuse. The RT investigates, in particular, the effects that an early mapping of the materials available in situ actives on the project, both in terms of optimization of the use of resources and of the material characterization of architecture.

A first test-bed of this approach in Italy has been the collaboration of the RT with architect Césare Peeren from the Dutch atelier Superuse Studios [9] in the restoration of a listed building (a private Villa) in the northern lake district in Italy, started in September 2017 and to be completed in October 2018.

At the same time, the RT is investigating this approach with the application of the harvest map tool to complex urban districts in Rome.

4.1. Refurbishment of a Villa in the northern lakes district

The intervention has seen the preparation of a harvest map in the area between Como and Milan to identify, among local companies, waste materials to be used in the recovery of a historic Villa in the northern lakes district, a listed building constructed with load bearing stone masonry and wooden floors. Preliminary geographic based researches and following surveys, conducted by a multidisciplinary team (coordinated by C. Peeren, with the collaboration of P. Altamura, E. Saturno - designer, D. Guzzo - photographer, and I. Inti - Polytechnic University of Milan) for the selection of potentially interested companies, have allowed to understand the characteristics of the flows of resources not reintroduced in the production cycles of the same or of other local companies. Thus it was possible to compose a

database of available resources (waste category, type of material, size, quantity and frequency of production, price), used to select the ones suitable for use as integrative layers of the envelope and of the vertical and horizontal partitions of the building and/or as components and materials for finishes and furnishings: fabric processing waste (defective silk and textile selvages); by-products derived from laser cutting of metal sheets; surplus production of metal sandwich panels; disused textile machinery, composed of various metal profiles; leftovers of mortars/resins for architectural finishes (figure 3).

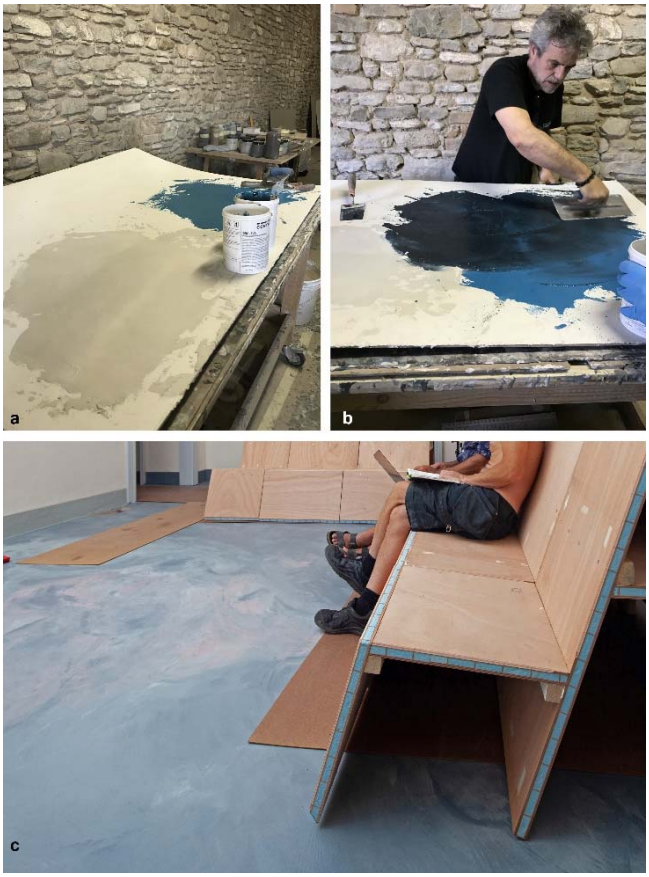

Figure 3. Leftovers of Malta (**a**), tested by the producer (**b**) and applied as floors finishing in the Villa (**c**). Photos **a,b** by P. Altamura, **c** courtesy of Denis Guzzo.

In particular, the reuse of leftovers of finishing resins was developed in collaboration with Stefano Mereu, the producer of a mono-component water based resin for floors and walls, called "Malta" (mortar). The product is characterized by a particular attention given to the different aspects of ecological sustainability in the whole process of manufacturing, production, application. The most relevant characteristic of the Malta, compared to standard resins, is that the two layers composing the finishing for floorings and walls are made of one-component water based polymers with very low VOC emissions in the drying phase (52 compared to 104 which is the maximum by law), and no VOC thereafter. Even the protective layer, which is the only two-component material considered dangerous in the transportation phase, once applied becomes VOC free. As concerns the production process, the Malta has no CO_2 nor other harmful emissions, since it is based on an auto-ignition chemical reaction without energy consumption. Furthermore, the raw materials used for producing the Malta are extracted in Piedmont and Lombardy, quite near to the production site which is in Emilia Romagna. The product was thus chosen for renovating the floorings of the Villa, using the leftovers of different coloured Maltas

used in other supplies, after a specific testing of the aesthetic effects developed by Cèsare Peeren with the RT and the producer.

The project has led to the opening of the Italian page of the open source portal *Harvest Map* [10].

4.2. A harvest map for the urban regeneration of the former industrial site Papareschi in Rome

The first application of a harvest map to the city of Rome was developed by the RT within a Master's Thesis conducted with the Polytechnic University of Turin, Italy [11]. The project was aimed at the recovery of the Miralanza factory in the former industrial site Papareschi, within the Ostiense - Marconi district (western part of the city centre), with the use of waste materials sourced on site. The team applied a process that - from the scouting phase - led to the creation of a harvest map, the redefinition of functions and spaces and the technological project of reversible building components with reclaimed materials.

The site analysis supported the design choices and the definition of the scouting phase of the materials and components to be reused in the intervention, collected in the harvest map (figure 4). The industrial vocation of the site was replaced by an artistic-cultural one, consistent with the Urban Planning Previsions. In fact, the project foresees the creation of workshops (for scenic design, activated by the reuse of waste) and exhibition spaces, with annexed services and places for meeting and sharing. The primary objective of reuse started from the preservation of the existing buildings and the removal of inefficient additions, with the recovery of materials and components for completion interventions.

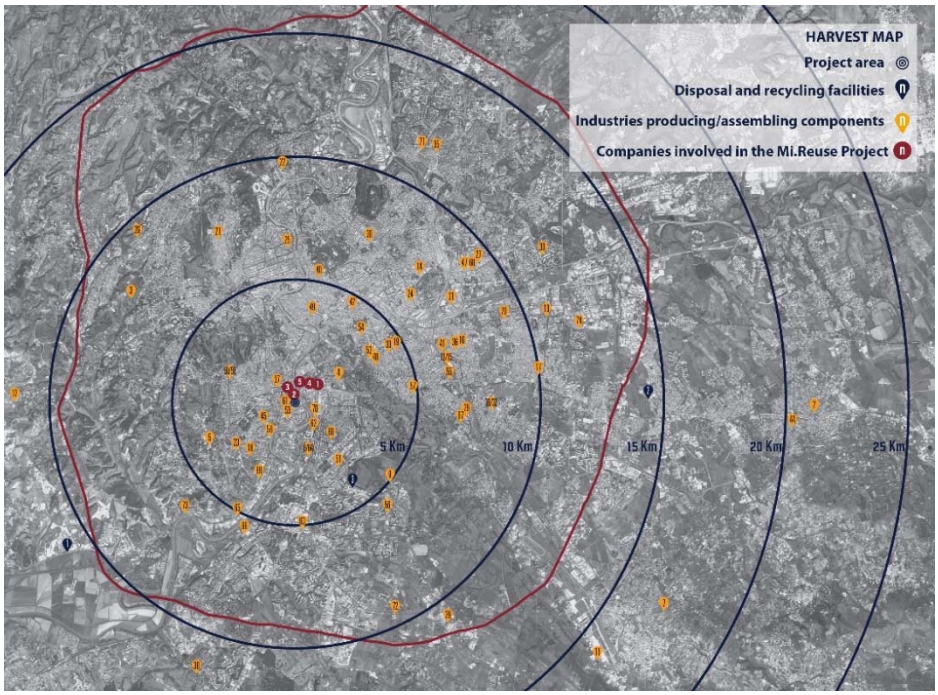

Figure 4. Harvest map focussing on the Papareschi Area in Rome (Italy).

Experimentation dealt with a landscape of considerable quantities of reusable waste, coming from construction and demolition sites, building residues from collapses, the presence of abandoned infrastructures (1 km of disused railway line) and waste from the commercial supply chain (paper, cardboard, plastic and nylon mix, pallets, textile scraps, bumpers), materials that can be recovered within 25 km of the project area. The definition of the harvest map was based, in the first phase, on the materials coming from the planned demolition of 2 buildings of the early twentieth century: bricks and tiles (whole and fragments, about 160,000 elements), easily separable and reusable. Furthermore, the collapse of the roofs of the former Miralanza left in situ tiles in fragments (56,000 Kg) reusable in *cocciopesto* (a Roman building material, made of tiles broken up into very small pieces, mixed with mortar and then beaten

down with a rammer) or as aggregates. For ferrous and wooden materials, since the ones present on site couldn't be recovered due to their state of conservation, a recovery company was contacted, with a factory located 13.5 km from the project area. The idea of the project was, in fact, to retain in situ all re-usable materials, sending out only the waste that cannot be included in the reuse intervention. The need to create a new roof, then, oriented the research on structures made with metal components, dry and disassemblable. Two accessible pavilions of the Fiera di Roma complex, abandoned and undergoing demolition, constituted an important "mine" for the project: steel pillars (54), removable and reassemblable reticular structures, metal tubular uprights for scaffolding (about 9,000) and other technical elements, not directly reusable, were included in the harvest map (PVC window frames). Another operation followed the recovery cycle of PVC sheets, reusable in the roofing system.

5. Discussion and research perspectives

These research experiences highlight the pros and cons of the implementation of circular strategies *through* design: on the one hand the increase in resource efficiency and the integration of the project in its material context; on the other, the lengthening of project times due to the preliminary research phases and to the current uncertainty in the interpretation of the waste regulations. Such conflicting factors need to be considered and balanced preliminarily. In this sense, the RT is currently working on the analysis and definition of the circular district Tiburtino in Rome: a feasibility study, from the harvest mapping to the design of a reversible building component. The complex structure of the area, with significant infrastructures (some of which in demolition) and buildings, combined with the incompleteness of parts of the urban fabric and the possibility of recovering two formerly craft/industrial settlements, offers an interesting study case to test the potential to start circular economy processes on a local scale, within the urban regeneration processes. By developing and prototyping a reversible envelope component for the recovery of existing buildings, made with reused materials, it will be possible to assess the increase in resource productivity and the technical-economic feasibility of a "typical" operation. The aim is to demonstrate how superuse and upcycling can represent reliable technical options widely replicable on a supply chain scale, not just as a single design experiment. In this sense, a very good example of how the reuse process can be turned into "industrialized" practice is represented by the work of Lendager Architekter on reused bricks modules [12], opening new research perspectives.

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