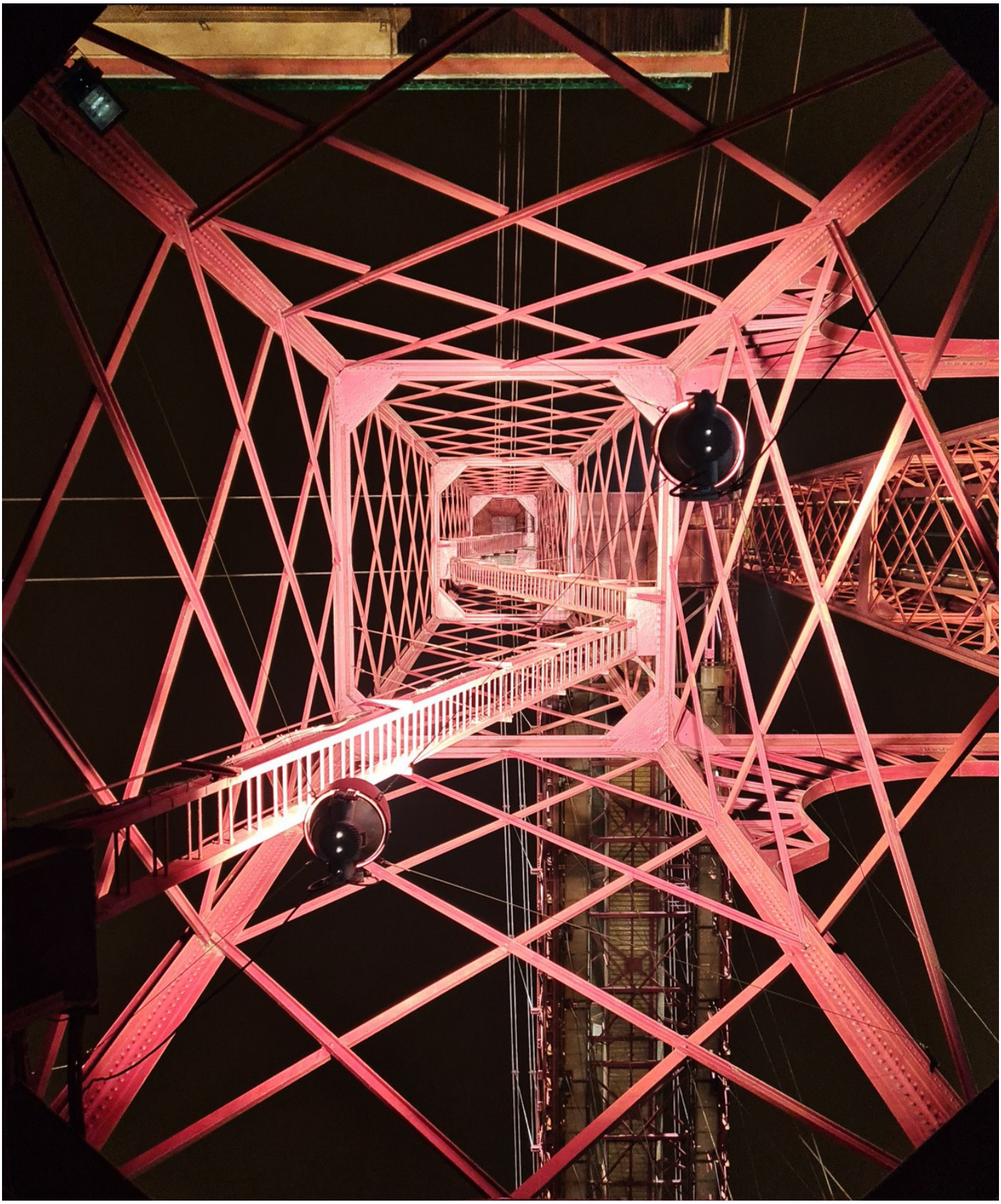

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THE DISUSED PRECIOUS STONE ELEMENTS ARE NOT CDWASTE. A DIGITAL MANAGEMENT CHAIN TO SAVE THEM

Raffaella Lione, Ornella Fiandaca, Fabio Minutoli, Alessandra Cernaro, Luis Manuel Palmero

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Abstract

One of the most significant contributions to the circular economy that has emerged at the EU level (EU Protocol 2016) is the optimized management of the entire construction and demolition waste (CDWaste) chain: from selective dismantling to reuse in the building process as materials/products/components. The aim of this study has been to contribute to this systematization process of the currently not converging but stimulating initiatives by proposing an investigation for the Valuable Stone Elements Waste (VSEWaste) chain, removed in the process of replacement operations. In particular, we note that they have a sort of added value that demolition does not cancel, both for the nobility of the raw material and the processing they received, which is not always replicable nowadays. So they deserve separate treatment in the broader field of advanced circular building design, capable of harnessing the full potential that this type of waste can still express.

On the basis of an analysis of the best practices pioneered in several EU pilot projects, the digitalization of all the management phases of this CDWaste class has been undertaken: specifying the most suitable production chain; implementing analog cataloging based on shared but specific criteria; drawing up, using BIM tools, an inventory of waste, to be assessed on a representative sample; identifying marketing systems for dismantled stone elements relevant to a given geographical area.

Keywords

Valuable Stone Elements (VSE) Waste, Marketplace, BIM (Building Information Model/Modelling/Management), GIS (Geographic Information System), Central and Maritime Station of Messina.

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1. THE DESTINY IN THE EUROPEAN COMMUNITY OF THE VALUABLE STONE ELEMENTS (VSE) WASTE FROM SELECTIVE DEMOLITION

In the cultural framework laid down by the European Union for the management of construction and demolition waste (CDWaste), it appears that the emphasis is directed mainly towards their recycling, as an activity that implies paths to turn them into resources through an end-of-waste process, and their feeding back into industrial production cycles [1–3].

For this study, attention was paid to a specific category of CDWaste, i.e., the valuable building elements that result from selective demolition; these do not necessarily have to undergo a recycling, energy recovery, or dumping process; instead, they can be reused through

minor adjustments. So, the focus was on fragments of stone artifacts, more or less remarkable, resulting from decommissioning, removal, and demolition in the context of interventions on the built environment that have appeared to be quite unrelated to safeguarding and protecting instances. There seems to be no urge to document these operations, let alone preserve for future generations the marks that natural aging and cultural history have left on these elements, imprinting unreproducible traces of our past that make them a precious resource.

For this reason, an early reflection addressed the concept of value, filtered not so much and not only through the quality of the stone material that characterizes these wastes but also through the rarity of the lithotype used, the craftsman's expertise (i.e., adherence to the best practice), the state of conservation, the dimensional parameters, and other factors that should be incorporated into the assessment of each fragment foreseeable fate.

It should be emphasized that construction and demolition waste introduced in the EWC code 17 class of the European Waste Catalogue (Decision 2000/532/EC) does not explicitly include stone materials, not to mention valuable ones. It is hence essential to highlight the peculiarities and importance of this category, which cannot be overlooked, let alone directed towards the most widespread recycling process, namely the production of aggregates. This vision would implicate only their crushing and use in embankments and backfills or, more rarely, as a prised aggregate in the formulation of mixtures for artificial stone (Stonethica and Catalyst from marble milling waste).

An overview carried out on some maintenance operations has pointed out two opposing tendencies: strict conservation of each stone element through removal, restoration, and reassembly, even if relocated; replacement after removal, with imitations (*simulacra*) being put in place, and indifference to what has been removed, considered as waste to be disposed of in landfills.

The first case, for which there is no question of the fate of the parts concerned, has been found in the context of historical architecture, whenever the concept of memory has prevailed over the pragmatism of the choices: relics are dismantled, collated and when not stored in a museum, put back in situ, or elsewhere, to reassert their historical-architectural value associated with the formal composition and/or the quality of the material (capitals, friezes, architraves, columns, etc.) [4]. In the second case, which has been proposed in many rehabilitation projects of 20th Century Architecture, disposal in landfills of the items removed has been – except in rare cases – the norm, as if artificial stone elements, thin slab claddings, litho-ceramic finishes, could not achieve a sufficient degree of interest for conservation or, at least, reuse in other contexts [5, 6].

Regarding the latter case, it could question the criteria employed for (Fig. 1):

- the maintenance throughout the years of the veined Carrara marble cladding of the Casa delle Armi at the Foro Italico [7] in Rome (Luigi Moretti, 1933-1937), where the detachment of slabs, set in *a sorella* pattern, without offset between joints as if they were a malleable plaster, has been partially braced with improper fixings made with nails or threaded pins;
- the complete replacement of the peperino slabs on the main façade of the Central Station [8] of Reggio Calabria (Angiolo Mazzoni 1936-1938), which were all discarded and disposed of in landfills;
- the successive substitutions of the Alcamo pinkish travertine slabs in the Central and Maritime Station [9] of Messina (Angiolo Mazzoni, 1934-1940) with different lithotypes and the waste storage occasionally used as a quarry for minor repairs;
- other instances where «in the last decades, these precious and vulnerable claddings have been subjected to various interventions that clearly show the widespread tendency to rebuild, restore and correct, rather than to find specific solutions to preserve material authenticity» [5].

The decision to return to a meaning congruent with the conservative instances, the one that should guide the restoring procedures for the operations of replacement of valuable stone elements, which belong to this

praxis, has prompted a second reflection: how the relics removed from the buildings could be returned to a global construction market, where they would cease to be waste and take on the role of a resource that could be used elsewhere, valuable precisely because of the added value layered on the material over time.

A futuristic topic entailing the digitized circular management of CDWaste has been explored here and

Rome. Academy of Fencing at the Mussolini Forum, Luigi Moretti 1933-1937. On the right, a detail of the stone cladding of the south façade in which numerous replacement slabs, misaligned or out of plane slabs and traces of mechanical fixings added over the years are evident. (Photos by M. Ferrero).

Reggio Calabria. Central Station, Angiolo Mazzoni 1936-1938. On the right, the rehabilitation worksite of the main façade carried out in 2018 and the façade with the new slabs in place. The original marble cladding has been "pulled down, demolished and thrown away" (left and right down photos by R. Castiglia, right up [8]).

Messina. Central and Maritime Station, Angiolo Mazzoni 1934-1940. On the right, a detail of the original Alcamo travertine slab cladding compared with others replaced during the maintenance work carried out (1960-2000 span). (Photos by A. Cernaro).

Fig. 1. *Maintenance interventions of 20th Century Architectures examined, which have produced slabs of valuable stone material disposed to landfills.*

specifically applied to a highly representative pilot study: the dismantling over time, due to inconsistent maintenance, of the stone cladding of Messina's Central and Maritime Station. The designer, Angiolo Mazzoni, purposely determined the railway complex identity through the choice of material, dimensions, arrangement, and texture of the slabs, as well as through their laying procedure.

None of these factors guided the ensuing works on the stone cladding, except for the rehabilitation after World War II, the only one in which an attempt was made to preserve the specific nature of the railway complex. The maintenance of the 1980s and the restoration of the 2000s disregarded any demand to preserve the original cladding. In fact, slabs of Tivoli travertine were used, or, in any case, travertine of a different color and texture, laid with vertical veining, often thinner than the original ones, with the reduced depth being compensated for by significant layers of mortar as an infill. In addition, there are hints of gaps or misalignments due to negligent workmanship, and, above all, there is an evident lack of concern for the fate of the replaced slabs, some of which are carelessly stacked nearby.

It is precisely to safeguard conservative instances that this contingency has been adopted as a paradigm for the circular management of valuable stone waste (in the specific case, the travertine slabs that will be disposed of), by envisioning a digital chain investigated from the selective demolition to the reintroduction of these waste building elements into a unique and innovative production cycle.

2. A VIRTUOUS DIGITAL CHAIN FOR CIRCULAR VSEW MANAGEMENT

Even if, in the past, people "built by destroying", at the same time, they "destroyed by building", meaning that whatever was demolished, pulled down, dilapidated, or deleted had seldom merely been wasted. Using *spolia* has been a constant feature in historical buildings that show cultural stratifications in which demolition appears as a productive stage in relation to the pursued transformation objectives [4].

A lost awareness, this one, which only the last century is attempting to revive by including it in the current concepts of sustainability – conservation of material and energy resources, reduction of emissions and waste – and of the circular economy that redefines the lifecycle of materials from "cradle to cradle". It is thus necessary not to set construction against demolition but to set it against deconstruction, an inverse and specular procedure that can lead, as far as possible, to a selective repurposing of the constituent parts, to be directed to different uses compatible with the inherent value of each of them.

In this sense, these valuable building components, when, for some reason, not restored and kept *in situ*, should be selectively removed and managed through a hierarchical digital chain, envisioned as consisting of four steps in a previous study carried out by authors based on state of the art [10, 11].

The Registry of dismantled stone waste is the first stage in prefiguring its reuse. The analog approach to classification criteria cannot ignore the value identifiers that each piece carries with it: rock type (waste code), quarry depletion, size and type of surface finish, state of conservation, and other peculiar data.

Digital conversion is a second complementary level that should assume reasonable scenarios related to each specific worksite. The aim is to keep in archive valuable stone building elements dismantled from their original site to protect them despite their decontextualization, sometimes questionable. The cataloging activity includes, as a priority, BIM modeling of the item to be decommissioned, with emphasis on the identification of the composing parts, points, or lines of reciprocal joining obtained from survey operations or the design documentation. Supplementary tools to parametric methodology will then allow each conceivable scenario to be virtualized through an easy implementation of abacuses to assess quality and amount and/or end-of-life assumptions to ensure effectiveness and viability.

At this point, the construction of a virtuous digital supply chain must reach the third stage by introducing each BIM-based inventory into a digital platform for commercialization where all the operators involved in the supply-demand pair could meet. Marketplaces, and

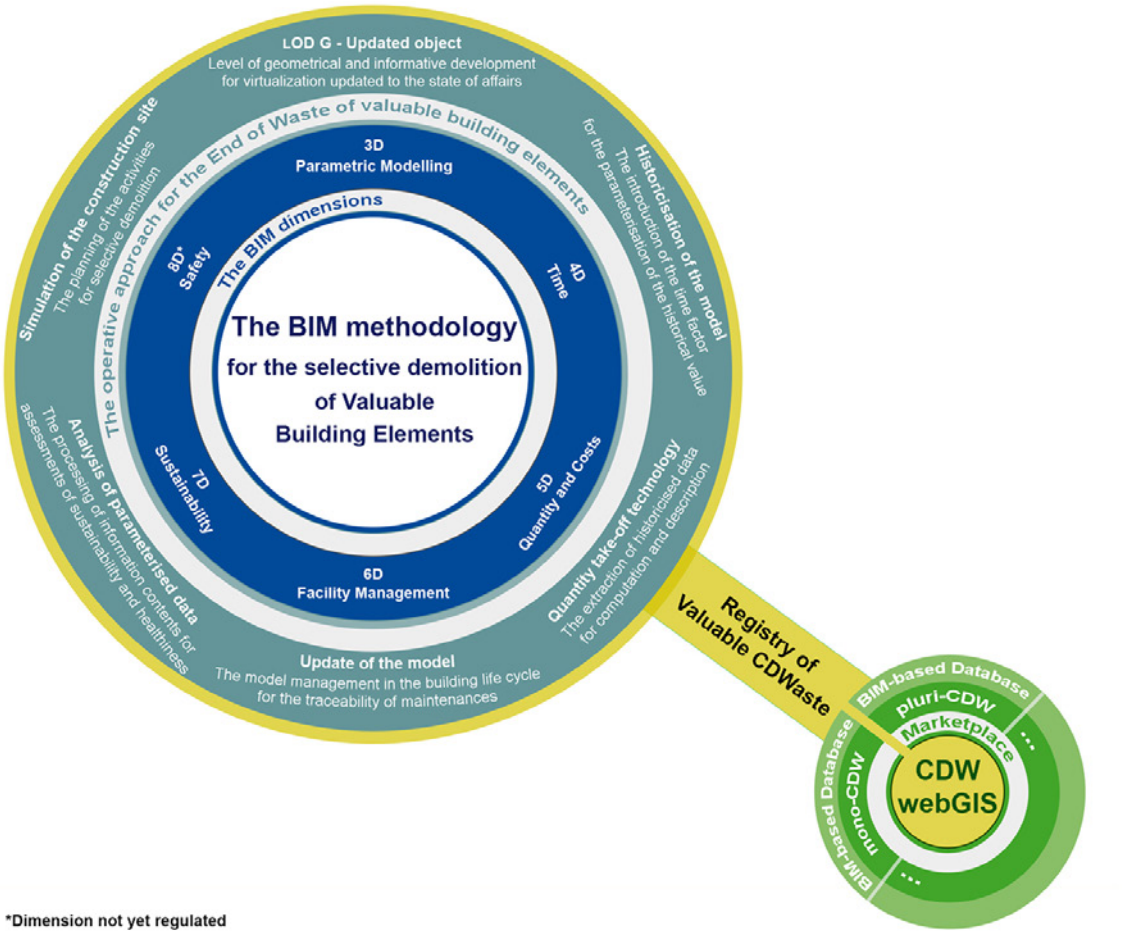

Fig. 2. *A first hypothesis of the supply chain for CDWaste digital management. (Drawing by the Authors [11]).*

those comprising construction and demolition waste, were thoroughly investigated to verify their functional structure, their correlations with structuring databases, the potential they hold, and the still unresolved loopholes to outline a hypothetical platform for VSEWaste.

Finally, but still in progress, the fourth tier of the hierarchy was addressed. It consists of a GIS (to be implemented as a WEBGIS) to determine its role and place in the digital supply chain, whether it should concern an inherent access part to the conceived marketplace or should be a container in which all the implemented and implementable datasets will be organized, through georeferencing (Fig. 2).

3. SUPPLY CHAIN STAGES FOR VSEWASTE DIGITAL MANAGEMENT

The phases, already developed as crucial moments of the investigation aimed at building the digital supply chain of valuable stone waste, are outlined below; for each of them, the results achieved and the effects on the case study of the methodology will be analyzed as follows:

- cataloging criteria for valuable stone elements;
- BIM-based Digital Registry of Valuable Stone Elements Waste (VSEWaste);
- marketing platforms modeled on marketplaces.

3.1. CATALOGING CRITERIA FOR VALUABLE STONE ELEMENTS

Recent developments such as teleworking, broadband, 5G, BIM and GIS software, and e-commerce are all equally emerging and competing premises in the development of the idea, which is presented here, to deploy the latest technologies to establish an open, continuously implementable and global market for some "scrap/

8. Recommended template for inventory of building element

BUILDING:								
Level:								
Other relevant information:								
Construction unit:								
Element	Units	Location	Reusable	Possible markets	Quantity	Materials identification and Waste codes	Precautions to take during the deconstruction phase	Pictures and notes

Materials present in the different elements should be detailed using the templates provided in section 8.

9. Recommended template for waste management recommendations

BUILDING:							
Level:							
Other relevant information:							
Construction unit							
Type of material	Waste code (EWC and EURAL)	Location	Possible outlets[1]	Recommended outlet[2]	Precautions to take during the deconstruction phase[3]	Handling precautions	Legal storage /transport/ treatment conditions

4 Reuse; recycle; backfill; energy recovery; elimination
5 The recommended outlet must be identified taking into account the hierarchy of waste treatment and the potential possibilities in the proximity of the jobsite
6 Ex: do not leave the frame on the plasterboards; be careful to remove the power plugs, etc.

Fig. 3. *EC cataloging tools for CDWaste management.*

waste" (authors' note: between quotation marks because these are not materials that can be classified in this way, but genuine resources, sometimes precious) of stone elements, which do not come directly from quarries or processing centers, but mainly from sites of work on existing buildings.

State of the art holds up promising trends aimed mainly at the entire lifecycle of buildings, for which a cultural revolution is called for right from the early design stages. In that sense, several projects and academic studies have developed the concept of the Material Passport [12], devised for a circular economy of the construction sector that does not disperse or discard waste. It recommends a relatively complete classification of the construction materials of each project, specifying their physical, chemical, and biological properties, without overlooking the ecological quality aspects linked to their entire lifecycle, up to outlining the framework of a document certifying their identity, healthiness, and potential end-of-life scenarios.

With a focus on the demolition and renovation stages of the existing building stock, the European Union has suggested templates for the inventory of building elements and component materials (Fig. 3) for a preliminary assessment of the waste generated. The rating criteria are geared towards a marketing policy that relies on summary descriptions of quantity, geographical area, EWC code, target, and potential markets [1–3]. At the national level, in Italy, only the Abruzzo Region, in 2010, for obvious reasons related to the earthquake that hit this territory, issued directives to reduce the production of construction and demolition waste by increasing its reuse and recycling (in compliance with LR 45/2007 *Norme per la gestione integrata dei rifiuti e s.m.i.*), entrusting the municipalities with the task of recording the waste produced within each intervention [13].

Not one of the criteria considered addresses the cultural value, which by going beyond the contribution of waste reduction to a global sustainability problem,

Minimum Documentation Fiche	Full documentation Fiche
1. Identity of building/group of buildings/urban scheme/landscape/garden	
1.1 Current name of building	1.1 Data for identification [current name; former/original/variant name; number(s) and name(s) of street(s); town; province/state; post code; block; lot; country; national topographical grid reference; current typology; former/original/variant typology; comments on typology]
1.2 Variant or former name	
1.3 Number & name of street	
1.4 Town	
1.5 Province/state	
1.6 Zip code	
1.7 Country	
1.8 National grid reference	
1.9 Classification/typology	
1.10 Protection status & date	1.2 Status of protection
---	1.3 Visually or functionally related building(s)/site(s)
2. History of building	
2.1 Original brief/purpose	*See 2.2 Summary of development*
2.2 Dates: commission/completion	2.1 Chronology
See 2.1 Original brief/purpose	2.2 Summary of development
2.3 Architectural and other designers	2.3 Relevant persons/organizations
2.4 Others associated with building	2.4 Other persons/events associated with building(s)/site
2.5 Significant alterations with dates	2.5 Summary of important changes after completion
2.6 Current use	*See 3.2 Current use*
2.7 Current condition	*See 3.3 Present (physical) condition*
3. Description	
3.1 General description	3.1 Site/building character
3.2 Construction	
See 2.6 Current use	3.2 Current use
See 2.6 Current condition	3.3 Present (physical) condition
3.3 Context	3.4 Note(s) on context, potential developments
4. Evaluation	
4.1 Technical	4.1 Technical
4.2 Social	4.2 Social
4.3 Cultural & aesthetic	4.3 Cultural and aesthetic
---	4.4 Canonical status (local, national, international)
4.4 Historical	4.5 Historic and reference values
4.5 General assessment	---
5. Documentation	
5.1 Principal references	5.1 Archives/written records/ correspondence
	5.2 Principal publications (in chronological order)
5.2 Visual material attached	5.3 Visual material (state location/ address)
---	5.4 List documents included in supplementary dossier

Fig. 4. *Comparison between the contents of the two forms introduced by the international cultural association DOCOMOMO to describe the heritage of the 20th century: the Minimum Documentation Fiche and the Full one.*

targets those identitarian principles inherent in certain essential traits of one culture or another, which must therefore be preserved. In this regard, it could refer to the activity carried out by DOCOMOMO (DOcumentation and COnservation of buildings, sites, and neighborhoods of the MOdern MOvement) for the conservation of 20th Century Architecture, which in two forms, one general and the other synthetic, has attempted to introduce the historical, architectural, and technical data through which the intangible cultural heritage would be described. These, too, have been considered in our pursuit of classification criteria for valuable stone waste (Fig. 4) [14].

In light of the overwhelming prevalence of the old over the new and the consequent exponential growth in maintenance work, which is by all accounts expensive, even too much so when compared to the current funds available for the construction sector, the approach of reclaiming and marketing all decommissioned or deconstructed stone materials appears to be a must.

This approach requires a methodological effort to identify classification criteria and suitable search keys to set up a kind of online market for stone fragments that can meet the needs of the building sector, avoiding wastage and the *ex novo* creation of pieces which, if new, would not blend easily with existing works.

In the proposed solution, a naturally homogeneous time frame has been singled out, that of the Modern experienced and manifested in the 20th Century Architecture, which in this first work hypothesis plays the role of a case model to test the effectiveness of the devised tool, which if "successful" could then be extended to other time spans.

Subdividing the filing of valuable stone waste by epochs allows them to be recorded according to a first homogeneity criterion, that of the techniques and tools with which these stones were crafted. This breakdown constitutes a critical factor for their reuse, capable of ensuring that the material is preserved in its broader meaning of material culture, which must also consider the modification received in a given period and in a given technical and technological context. The chronological perspective appears, in this respect, more relevant and of more significance than the geographical one.

In order to calibrate the digital management chain under consideration here, it was considered correct to ask ourselves what specific goals the chain should pursue in addition to the general one of reducing/recovering/reusing waste. Furthermore, the question was to what categories of users it should be destined to, but also what existing digital tools could or should be referred to and, consequently, what characteristics/properties of materials were to be considered.

The answers, apparently self-evident, are far from obvious and prompted many afterthoughts and refinements as the details came into focus. Actually, the choice of methodological approaches, such as BIM and GIS, was fairly predictable, and yet not without consequences and rather constraining; the possibility of envisioning a multifunctional system capable of equally satisfying the needs of a variety of users has been recognized primarily in researchers, designers/buyers, demolition specialists, not excluding other operators in the supply chain with tasks of storage, repair, restoration, etc., has proved more challenging.

These prerequisites have informed the definition of the classificatory categories of the stone elements to be filed, mainly as two-dimensional but also as three-dimensional form, pinpointing the key aspects to be incorporated to enable a digital management that, as desired, could be open, flexible, and plural:

- based upon the intrinsic characteristics: mineralogical identity, provenance, dating;
- based upon the previous locations: building element type and position;
- based upon the characteristics of the single piece: geometric configuration and processing techniques.

Without overlooking the fact that a true "virtual shop" is to be implemented, a sort of identification with the needs of the assumed user figures was deemed necessary, which led to considering: some historical-critical specifications to suit the scholars identified with the category of researchers (e.g., some data on the originating building); or some specific details that may be relevant for designers/buyers (such as those related to the specifics of the single pieces or the previous destination, but also the available quantities); or again, indications for the category of demolition specialists or other companies implementing other supply chain activities (e.g., the EWC code, although this is currently too general, and risk factors). A further consideration concerns the players involved in the dismantling sector because it is believed they can draw ideas both from knowledge and inclusion in a digital management chain of this waste if not real programmatic and pragmatic indications to better set up the deconstruction plan.

This consideration determined the information structure of the "operational tool" designed for this study (Tab. 1).

Each data necessary to implement an objective and effective database to return the extreme variability of valuable stone waste must respond to specific information characteristics which, in compliance with protocols or standards, make the content objective and repeatable.

In the absence of a currently shared international perspective on the problem, operational tools have been deduced from other sectors that propose solutions to the identified gap, albeit in a transitory form (Cf. Note to Tab. 1).

Parameter	Description
BASED UPON THE INTRINSIC CHARACTERISTICS	
Material type	Natural/Artificial
Stone class	If available, petrographic and mineralogical aspects
Colour	Identifiable shade or dominant tonalities
Quarry	Locality, Denomination, GIS Coordinates, Active/Closed
Quarrying date	Exact date, if available, or estimated dating
BASED UPON THE PREVIOUS LOCATIONS	
	Function and position with respect to the building
Interior/Exterior	Interior, exterior (exposure NSEW), both
Supporting structure	Wall/Arches/Vaults/Columns/Piers/…
Cladding	Floors/ Wall facing/…
Decorative element	Bases/Pilasters/Capitals/Friezes/Cornices/Corbels/Furniture/…
Previous re-use	For an element with a possible previous use
	Information about the building of VSEWaste origin
Name of building	Actual denomination
Variant or former name	Original or different denomination
Original use	Original intended use
Current use	Actual intended use
Address	Name of street, Postcode, Town, Province, State
Geolocation	Latitude, Longitude
Original Customer	Appellative of the original building owner
Actual Customer	Appellative of the current building owner
Designer/s	Name, Surname, Qualification
Company/ies	Denomination
Dates of commission and completion	Exact date, if available, or estimated dating
Stylistic features	Architectural current
History of building	Brief Construction History
Significant alteration	Intervention type (Ordinary or extraordinary maintenance works/ Volumetry variation/…), exact date, if available, or estimated dating
Current condition	Excellent/Good/Fair/Mediocre/Bad/Vary bad
Principal references	Main archival, bibliographic, photographic sources
BASED UPON THE CHARACTERISTICS OF THE SINGLE PIECE	
	Geometrical features
Type	Ashlars for Supporting Structures Ashlars, Slabs, Tiles for Claddings Mouldings for Decorative elements
Dimensions	Greater side, Smaller side, Thickness, Radius, … Other parameters related to the specific geometry of the element
Volume	To count the total volume of pieces with similar features
Shape	Regular/Irregular
	Production features
Primary processing	Related to extraction from the quarry
Secondary processing	Related to obtaining the element from the quarry block
Surface finish	Smoothing/Polishing/Bush hammering/…
	Historical phases
Phase "Created"	Moment of laying
Phase "Maintened"	Moment of maintenance
Phase "Demolished"	Moment of removal
	Conservation
Conservation state	Excellent/Good/Fair/Mediocre/Bad/Vary bad
Photographic records	To document the state of conservation
	Riskiness
CER CODE	CER 1709 "Other construction and demolition waste" is currently applicable, although generic
Other factors	Other aspects related to the riskiness
	Technical features
Measured parameter (1)	Result of the test carried out
Measured parameter (2)	result of the test carried out
…	…
Attachments	Documents of the test carried out

Notes The textual content requires no further specification. Concerning the iconographic apparatus that must reproduce the quality of the decommissioned stone resource in terms of chromatic, textures peculiarities, as well as the state of preservation in terms of the presence of anomalies, patina, degradation, reference should be made to international conventions or, in its absence, to specially designed guidelines.
For digital photographs, the 2016 F_version 4.0 form of the MIBACT_ICCD was considered a valid reference by appropriately declining the required guidelines: 1) file compression/extension format: .png for web-based viewing; raw for post-production; .tiff for professional viewing; 2) visualization, storage and processing program: Adobe Photoshop type or similar; 3) color depth: RGB or CMYK; 4) resolution 72 dpi for web and 300 dpi for quality faithful reproductions; 5) technical specifications: orthogonal shot of which to provide distance and color control device (ColorChecker) to carry out any post production operations [15].
The coding should be alphanumeric including place-type element-number shot-chronology.
For graphic conventions with which to describe degradation, if the photographic repertoire was not sufficient, the national and international normative panorama consulted was not considered effective and a specifically designed information convention was used.

Tab. 1. *The criteria adopted for the cataloging of valuable stone elements.*

3.2. BIM-BASED DIGITAL REGISTRY OF VALUABLE STONE ELEMENTS WASTE (VSEWASTE)

In order to optimize resources and results, the digitalization of the construction sector is leading to the reconfiguration of the entire supply chain processes in search of innovative approaches with a forecasting function to evaluate the envisioned solutions before their actual implementation. The CDWaste sector is no exception [10, 16–18]. The informative vocation of the BIM methodology, stemming from the possibility of associating data to the geometric-threedimensional virtualization of a building element, is driving the conception of the Material Passport [12, 19], the cataloging tool, which is conceptually close to the proposal here presented to encourage the reuse of valuable stone elements. However, this identification tool, since it does not include historical and cultural data, which instead for the particular category under consideration should be assessed in the same way as purely technical indicators, cannot provide solutions for its parametrization.

This led to a specific nature of this research, aimed at attaining the BIM-based Digital Registry of Valuable Stone Elements Waste, both tailored to the multidisciplinary parameters selected to provide a detailed description that would meet the needs of the various kinds of users and targeted towards being used by marketing platforms.

The hypothesis of a restoration work envisaging the selective demolition of the envelope cladding slabs of Messina Central and Maritime Station allowed the outlining of a methodological path that can be applied to similar cases and, with the appropriate generalizations, to other classes of CDWaste to be preserved.

The Autodesk Revit 2022® software has been selected for the pilot study, as it is the most widely used parametric IT tool at the international level for research purposes. Depending on the content and operational requirements outlined, a procedure consisting of the following phases has been laid out:

1. an in-depth documentary and diagnostic investigation to acquire the information for a multidisciplinary characterization of a building's valuable stone elements (Fig. 5);
2. the parametric modeling of the actual state of each element by conceiving a specific BIM object which represents the geometric configuration and whose informative content reflects the established classification criteria, including those aimed at its inherent historical and cultural heritage value (Fig. 6);
3. the implementation of a preliminary "Registry of valuable stone elements" of a building, that is to say, in the BIM perspective, an abacus that gathers the cataloging of all the edifice's stone pieces and that serves as a support based on the systematized knowledge, to plan the maintenance and/or start pre-demolition audits (Fig. 7);

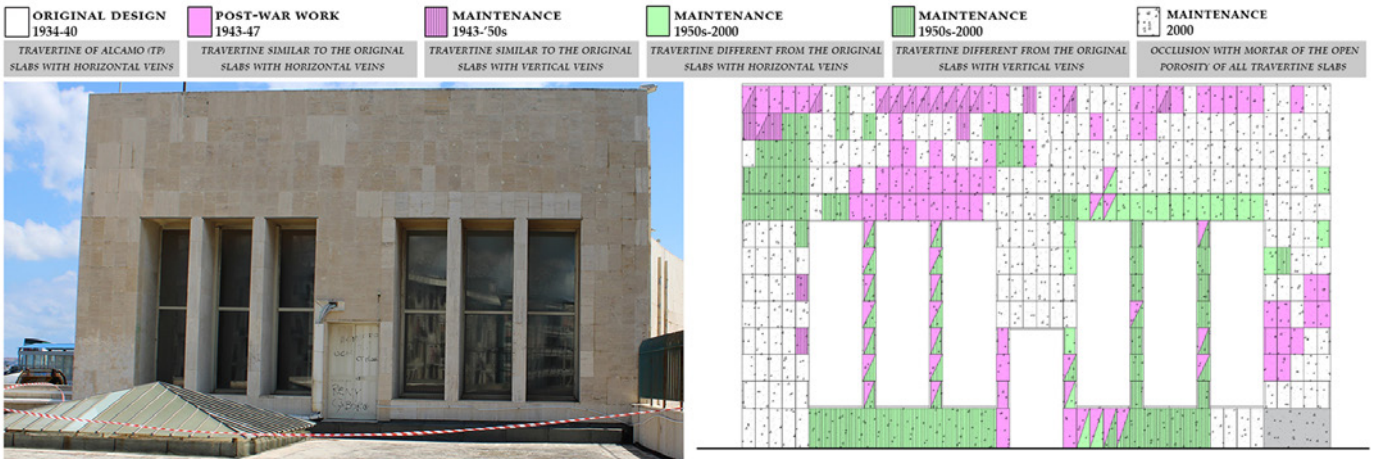

Fig. 5. *An emblematic elevation of the Messina Maritime Station: the mapping of replacement and maintenance work on the slabs as it results from the documentary and diagnostic survey.*

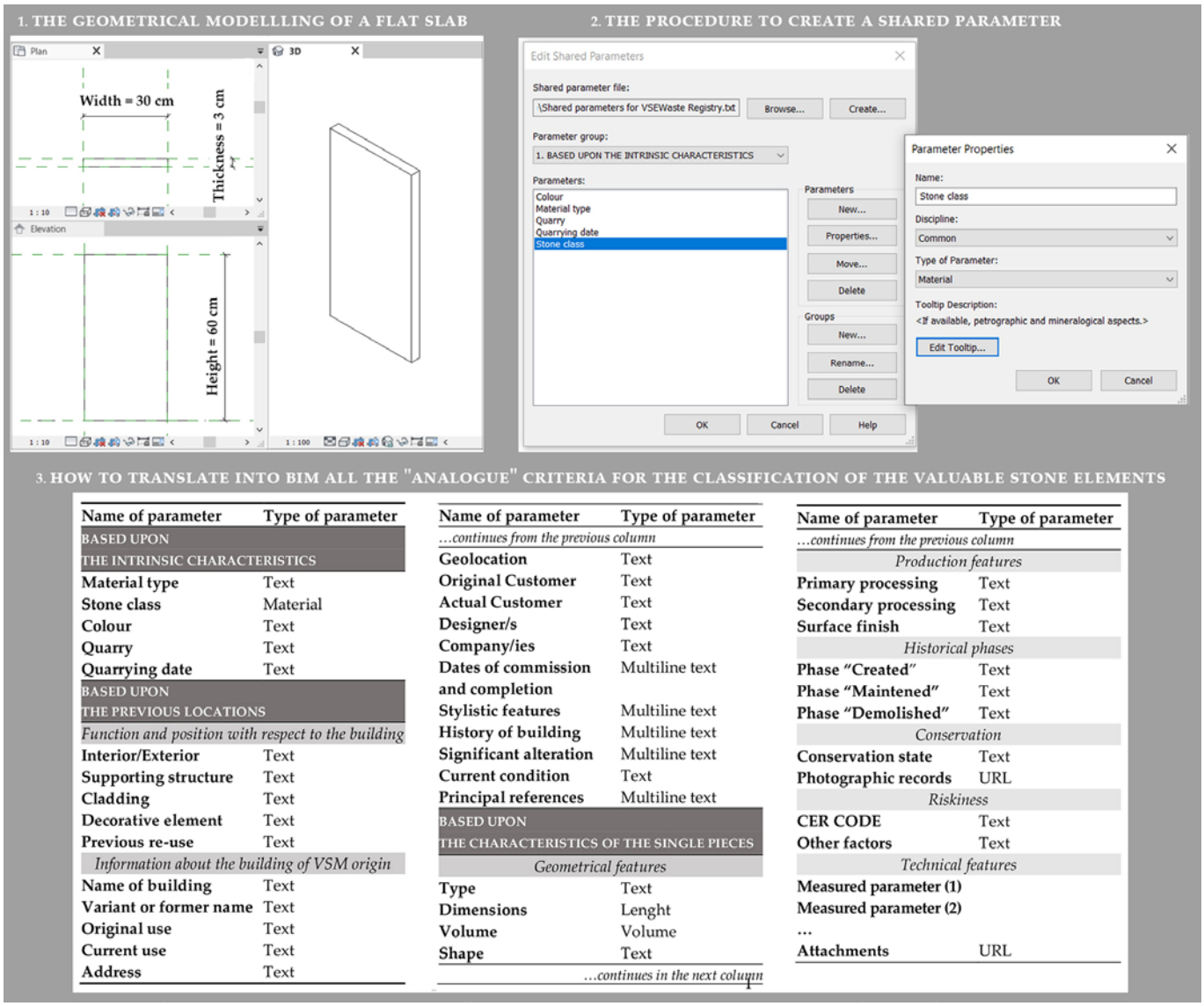

Fig. 6. *The BIM object of the travertine slab at the scale of the LOD G: the geometric modeling of the stone element in its actual state and the informative modeling through the definition of multidisciplinary parameters, including the historical-cultural data.*

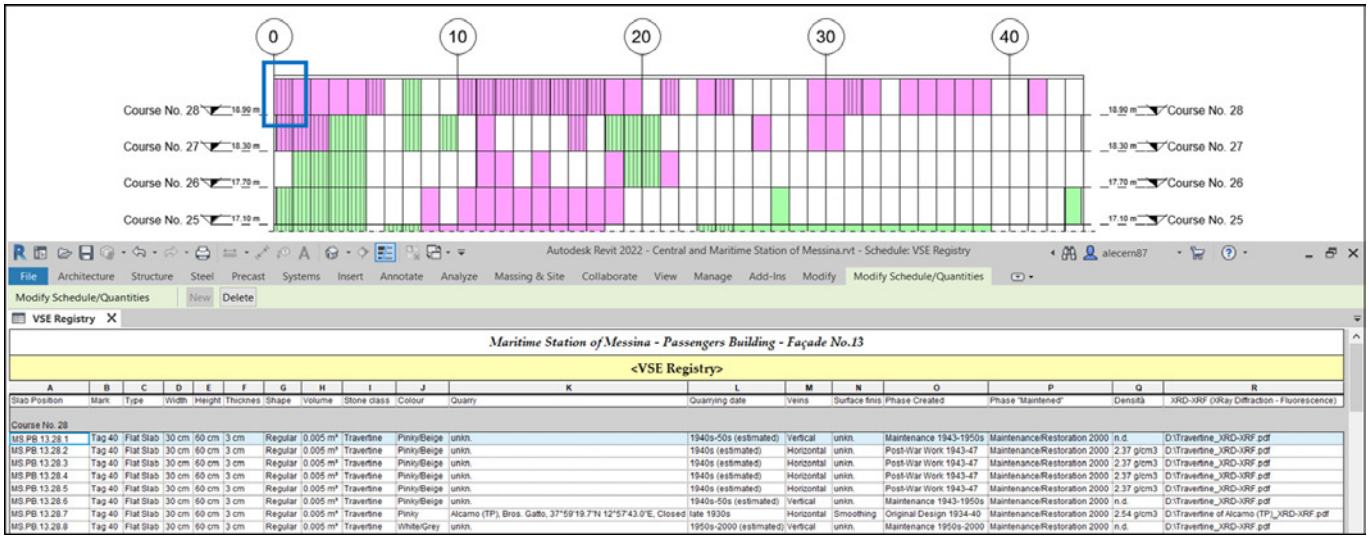

Fig. 7. *The Registry of the valuable stone elements of the Messina Station envelope cladding: the systematization of the documentary findings and diagnostic surveys aimed at supporting management plans and/or pre-demolition audits.*

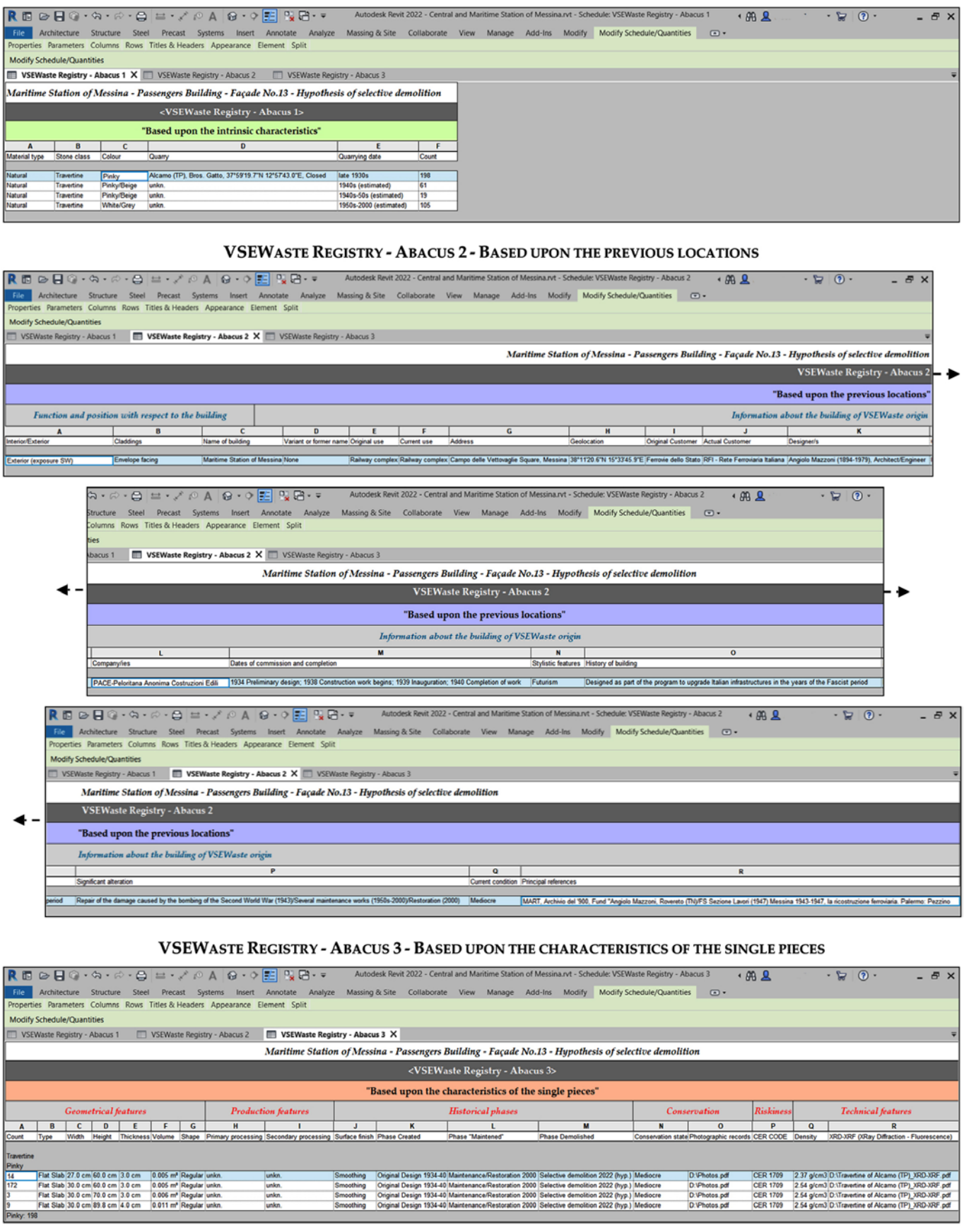

Fig. 8. *The Registry of Valuable Stone Wastes: the thematic abacuses, sorted according to the three cataloging criteria, can be retrieved in the databases of the marketing platforms.*

4. the extraction of the "Registry of valuable stone waste" from the previous and general inventory tool in order to gather the data of the pieces affected by the selective demolition intervention in thematic abacuses that can meet the query needs of the various kinds of users through commercialization platforms of which, in the later part of this paper, the simulation of an application will be illustrated (Figs. 8, 11 and 12).

3.3. MARKETING PLATFORMS MODELED ON MARKETPLACES

In the process of the digitization of CDWaste management [20–22], it is essential to thoroughly investigate the topic of sharing platforms; to verify their current development, the hypothesized structures, their limits, and their potential. The upcycling that, in this field, can be triggered by marketplaces is now indisputable, yet their presence in the construction waste sector is still somewhat limited and does not take off.

The literature of the last decade (2010-2021), published in Scopus, Web of Science, and ProQuest databases, has been systematically analyzed, along with the classification and ordering of marketplaces dealing with the construction sector, in order to get an overview of the trends in scientific production and to analyze those factors that are crucial for a sector-based and IT-based conduction of construction and demolition waste/resources [23].

In the last two years, scientific production has increased by more than 30% over the previous years concerning the general topic of CDWaste reuse; 33 articles were selected for the specific considerations of this study, which numerically highlight the emerging nature of this field of investigation. These papers deal specifically with materials such as concrete (n = 13), bricks (n = 7), steel (n = 5), wood (n = 4), plastics (n = 3), glass (n = 1), for which, according to the authors, an easier path to reintroduction into the waste-resource chain exists. They can be divided into four research branches: 1) management methods, 2) benefits of using e-commerce, 3) models for an online marketplace linking sellers and buyers, and 4) constraints and potentials of a CDWaste marketplace.

Similar results emerged from the web survey of marketplaces, which highlighted many differently originated experiences that had been developed for:

- facilitating the recycling/reuse of a specific type of waste, the so-called "vertical waste";
- classifying, storing, and reselling materials or elements from rehabilitation interventions;
- offering exchange platforms and expert services referred to as "horizontal waste";
- linking scrap/waste producers with recyclers, retailers, and users.

The trend, as evidenced by the analysis of the scientific literature, describes a market aimed at concrete, brick, steel, and plastic components, for which there is the greatest demand for a second-use life, mainly resulting from recycling actions. Stone materials are equated to rocks or aggregates.

The specific features of the twenty-four marketplaces active on the international scene were analyzed, and three core categories were identified:

1. platforms for the dissemination of circular economy principles that act as interfaces between supply and demand by working on projects, assessing/selecting requests of the best offer on the market, and looking for the most suitable market for a given offer (Business to Business – B2B);
2. platforms where alongside an e-commerce catalog, there is a customer facilities section (Business to Consumer – B2C or Consumer to Business – C2B);
3. consumer-to-consumer platforms, such as eBay, where photo ads are posted to meet supply with demand (Consumer to Consumer – C2C).

To understand which kind of structure should be given to the VSEWaste e-commerce platform, it is therefore essential to determine the specific properties of this

SALVOWEB, B2C started in the UK since the 1995

CYRKL, B2B d start-up in the Repubblica Ceca since the 2015

Fig. 9. *Retrieving rare stone elements from active marketplaces.*

particular section of CDWaste (classification criteria); the nature of the production basin (generation, storage, transformation places); the benefits and advantages associated with this organization mode through e-commerce (BIM-based Registry); the end users' profile. Only after these assessments have been performed can the best management mode be determined and the specific marketing platform structured.

An initial search for sections related to valuable stone elements within these instruments revealed a minimal presence, a territoriality of exchange confined by transportation reasons, a lack of data beyond quantities, and only sometimes of the exceptionality of waste.

The few examples found are illustrated here above (Fig. 9).

Concerning valuable stone waste, affected by the depletion of raw materials, obsolete and uneconomical work methods, and the lack of availability as a result of the policy of replacing rather than restoring, most notably in the field of 20th Century Architecture, it appears appropriate to imagine a platform conceived for reuse paths and, only if not achievable, recycling, in order to turn them into a resource again.

Designing an e-commerce tool dedicated to this class means choosing the most suitable structure which, as illustrated, follows four management methods: B2B (business to business) marketplaces between companies; B2C (business to consumer) between companies and consumers; C2B (consumer to business) between consumers and companies; C2C (consumer to consumer) between consumers.

In the CDWaste field, the surveyed platforms for mono-materials fall into the B2C category, i.e., waste collection consortia that interact with end-users. Those related to urban regeneration are of the C2C or C2B type; this means that large amounts of waste are offered by those who generate them as part of the selective demolition of large housing estates (not always digitized) to those who will then reuse them. The last category is predominantly B2B that are exchange platforms, from producers/collectors to storage and/or repair operators and then from these to consumers; they include complementary expertise services for companies willing to introduce circular economy principles in their waste sector.

The organizational model of a marketplace for VSE-Waste could be a combination of the four types (C2C; C2B; B2B; B2C). By having a waste producer as the origin and being directly addressed to other end users or to companies that take care of some repair/restoration interventions (resinating and plastering of slabs; cutting them into pieces of different sizes; addressing some forms of degradation, etc.) before returning them to the consumer's market. However, in this study, it was considered essential to add a supplementary category

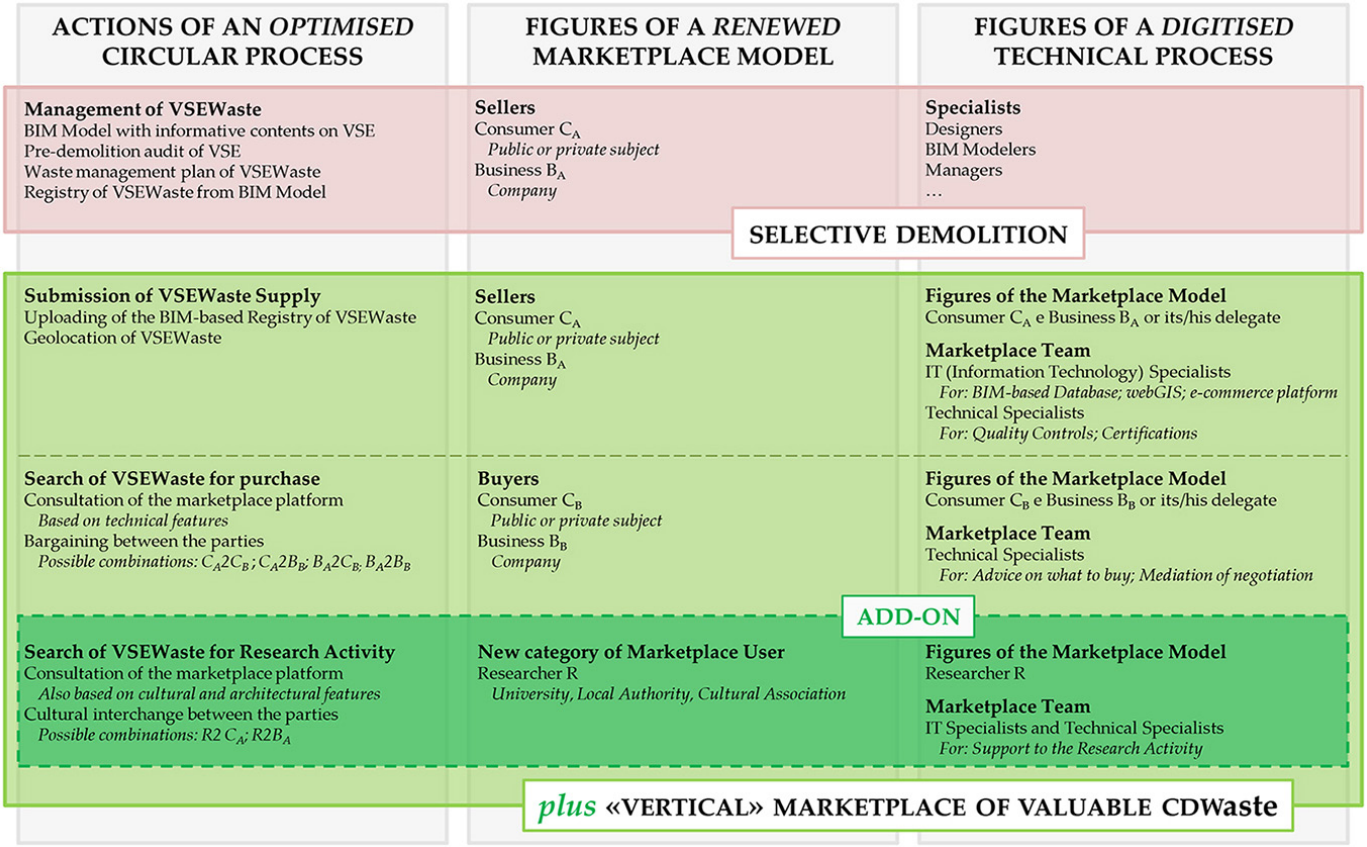

Fig. 10. *VSEWaste trading platform.*

of users, that being researchers (universities, local authorities, cultural associations) who, by exploring and understanding the subject, could lead and promote the spread of a culture of conservation and reuse of these "*spolia* materials".

Moreover, as already noted above, by reviewing the current virtual showcases of reusable CDWaste, an almost absolute lack of information emerges for an in-depth functional evaluation prior to their purchase, which cannot be missing in the case of valuable stone elements derived from selective demolition. For this motif, an interface tool was conceived that provides a reasoned inventory of VSEWaste generated through BIM methodology.

The general structure conceptualized for the platform is above (Fig. 10).

A simulation complements the proposed conceptual revision of the marketplace structure to provide an example of what the operational implementation might look.

The marketplace featured differs from the solutions found on the web in its target audience and in its strict dependence on the data associated with the BIM model of the building from which the valuable waste originates. Moreover, it also builds on the future CDWaste WebGIS platform. From the envisioned homepage, three paths should be possible, structured according to the objectives of the end user and based on progressive steps: "Let's sell", "Let's buy", and "Let's study" (Fig. 11).

The add-on path for Researchers, "Let's study", is displayed below: it has been introduced for the very first time in the course of this study for the Researcher R category (university, local authorities, cultural association), a new figure in the marketplace context; this category will be able to use a direct monitoring tool on the marketing of valuable CDWaste for research purposes or for orienting circular recovery/reuse policies, with the opportunity to refine the search by keywords (designer, style, timeframe, site, intended use) and then

Fig. 11. *The simulation of the marketplace "Valuable CDWaste". From its homepage, the three paths: "Let's Sell!" for Consumer CA e-Business BA; "Let's Buy!" for Consumer CB e-Business BB; "Let's Study!" for Researcher R.*

further deepen it by downloading the BIM abacuses entered by the CA/BA user. So, the platform's usage has been simulated through a scenario of selective demolition of a façade of the Maritime Station of Messina cladding slabs, for which the VSEWaste BIM-based Registry is provided (Figs. 5–8). It was supposed that the Archaeology, Fine Arts, and Landscape Superintendence for the provinces of Siena, Grosseto, and Arezzo, has to provide guidelines for a (hypothetical) restoration of the pinkish Villanova (SI) travertine cladding of the Siena Station. The cladding was designed by the same Angiolo Mazzoni, for which it could consult the marketplace to check the scope of slab supply from a building with comparable historical-architectural peculiarities (Fig. 12).

4. BARRIERS TO THE CIRCULAR MANAGEMENT OF THE IMPLEMENTED TOOL AND HYPOTHESIS OF OVERCOMING

The dealing of CDWaste, from their generation to integration as a resource, in essence, presents the critical issues attributable to:

Fig. 12. *The simulation of the marketplace: the path "Let's study!".*

- cultural barriers, a lack of awareness/discomfort with the waste problem;
- institutional barriers, absence/lack of oriented policies and regulations;
- operational barriers, disorganization/fragmentation of supply/processing/ marketing chains;
- digital barriers, inadequacy/ deficiency of BIM digitization of the historic-architectural heritage;
- commercial barriers, and lack/neglect of an effective market for matching supply and demand.

The digitalization of an infrastructure, such as the one elaborate, which starts from the places where CDWaste is produced, in this case, VSEWaste, and goes all the way to the conception of a georeferencing system of the operators involved in the processes of selective dismantling, recycling/reuse, and marketing, is definitely a fundamental part of the environmental issue with the introduction of circular economy criteria aimed at addressing the entire lifecycle.

However, the effectiveness of the proposal presented lies not only in the inclusion of a single conceptual framework of the entire chain, including all the operational and commercial figures concerned but also in having to encompass the cultural grounds by providing accessibility to researchers. Their action of exploring and deepening the process may include, besides the potential of digital management of VSEWaste, also the limits that can be identified in the following issues:

- the dissemination of a new cultural and strategic approach triggered by the synergy between ecological transition and digitization of processes;
- the management of this digital application, carried out by an entity, whether institutional or corporate, but uniquely in charge of the implementation and protection (control, supervision) actions from a legislative, procedural, operational, perspective, etc;
- the funding of the entire sector, including its digital transition (BIM, Marketplace, GIS), with incentives to make the adoption of a different cultural model “attractive”;
- the preparation of information models of historical heritage buildings, in addition to serving for maintenance actions, could be optimized to facilitate obtaining the Registry of Valuable Stone Waste if conducted with a view to the Material Passport.

Surveying the marketplaces operating in the field of waste has highlighted some significant factors: a structured running by Local Authorities that see in this marketing tool the possibility to implement ZeroWaste strategies; a geographical perimeter that paradoxically reflects national and not global boundaries; the total absence of shared parameters for an informed choice.

Accordingly, one of the main important points has been the consideration that the envisioned instrument had to open to the intellectual panorama in a bid to entrust to cultural management, even before that regulatory or political, specific intangible assessments concerning ecological benefits, digital advantages, safeguarding requirements, etc.

A further observation concerned geographical boundaries: it is desirable to have a window on the world, but the mobilization of VSEW needs to define its radius of influence, both reasonable and commensurate with logistics and transport rates. The perimeter, even for government conduction, should be, as in the US case, georeferenced, highlighting, on variable kilometric ranges, all the operators that enable the implementation of an organized process: from the construction sites to the places of conservation/storage and rehabilitation (repair, restoration).

Last, yet that structured the tool in its earliest formulation, is the consideration of the informative apparatus, which is currently very reductive in these systems of running waste. Although digital methodologies have been available for quite some time now, applications have not yet been conceived that can support different scenarios and variable management plans in relation to criteria determined on a case-by-case basis. This has led to the adoption of a BIM-based VSEWaste Registry, which down-stream of a demolition worksite modeling, which may soon become State Law, can automatically provide the Passport Material, adopted as early as the design stage of the building, to keep track of the stock of resources available throughout the whole lifecycle of buildings. Its transposition to existing buildings is what

has been attempted in this study to assess its effectiveness with reference to a theme – the decommissioning and restoration of modern architecture – and then to a specific case: the reuse of stone slabs decommissioned during maintenance work on representative architectures.

In the short term, it is difficult to imagine the implementation of a new technological-productive chain for these specific resources due to the absence of appropriate investments; policies promoting selective dismantling; involvement of the territory and the businesses in the development of a circular economy; deterrent taxes on landfill; an institutional culture; technological and information cooperation between start-ups and companies able to foster new future business models; a government policy able to regulate this fledgling market, through regulatory acts and economic-commercial criteria [24].

However, it is possible to benefit from an operative transfer from related fields. The digital platform Tech-Marketplace, which has been active since 2015 in the energy/sustainability/smart building fields, works in this direction by showcasing innovative start-ups and SMEs to establish effective partnerships; providing support for "anticipating change" by describing emerging technologies and industry trends (updated to 2019).

The CDWaste sector would require an incubator capable of systematizing the best practices in the institutional, cultural, operational, and commercial domains to structure an effective management system.

5. A SHORT-TERM OPERATIONAL PROGRAM

Implementing the proposed approach to manage the fate of decommissioned valuable stone elements, and in general for CDWaste to be preserved, requires procedural changes that must be operationally concerted in short-, medium- and long-term programs. Downstream of all that has been experimented with, the methodology articulated in the four phases illustrated should be considered a correct practice to achieve when fully operational due to a normative, cultural, and professional coordination leading to the layering of progressive digital information, functional to knowledge, preservation, and enhancement of the architectural heritage, in the case under consideration the Modern one.

An immediate development for the protection of decommissioned valuable stone elements, imagining their reinsertion in a commercial circuit as spoliation material, may involve the preparation of a digital register, starting from the analog catalog, in view of a complete Materials Passport derived from H-BIM/GIS oriented reproductions of each architectural asset. This first product, with scientifically prepared textual and iconographic specifications, in place already drafted for the pink Alcamo travertine cladding of the Messina Maritime Station, could be included in a dedicated marketplace with commercial but also cultural values. This implementation could allow the public (MIBACT, UNESCO, etc.) or private (DO.CO.MO.MO, GBC Italia, etc.) management protection that follows the cultural heritage of our architectural heritage for the entire life cycle, from cradle to cradle.

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