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Reversible Design: Strategies to Allow Building Deconstruction and a Second Life for Salvaged Materials

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ABSTRACT

This research investigates an eco-friendly design procedure, that we will name reversible design, that facilitates the recovery of building materials and components in order for them to be reused or recycled at the end of a buildings planned service life. The study focuses on how the design process must be organized and which decisions are especially important to obtain an eco-friendly end-of-life of buildings. The current Italian housing production is analyzed in detail, due to its current high ecological footprint, combined with an intense change in living styles, as well as in the configuration of space.

According to scientific literature, several effective strategies can be adopted during the initial design phase that will allow an easier future deconstruction of the building elements, with maximum recovery of material resources for a second useful life.

The available tools to evaluate buildings end-of-life scenarios are investigated, pointing out their specific procedures and goals.

DESIGN FOR ECO-FRIENDLY END-OF-LIFE SCENARIOS FOR BUILDINGS

The main question answered by this research is how design decisions of a building can allow for an eco-friendly end-of-life for residential buildings in the context of contemporary Italian construction. A context in which the building production is characterized by high ecological footprint and intense demand of functional flexibility, with a short term changing in living spaces [Kronenburg, 2006]. The fast evolution of lifestyles and household social structure demands that living spaces also increase their adaptation and transformation. Because of the older age of housing in current use (more than 30 years on average, with 40% built before 1961), the needs of adaptation have caused an intense activity in refurbishment and therefore a subsequent and widespread large production of construction and demolition waste.

Short-term use of buildings, or parts of buildings, reduces the useful lifetime and therefore produces an increase of wasted building materials and components, with hard environmental impacts at the end of a building's life.

A critical relationship therefore emerges between the improvement of housing standards and the environmental impacts these improvements produce in terms of early and massive resource consumption.

As discussed in research carried out in Italy during the last few years, the problem can also be observed when the modifications to a building are targeted to improve the environmental building quality, such as energy efficiency through the application of thermal insulation or replacement of the windows. The negative impacts related to the old elements being decommissioned reduced the intended positive environmental effect of the modifications.
A more ecological approach to the resources and materials used along the whole building life cycle (from extraction to dismantling) needs actually more investigation and more concrete and spread application, such us more performing decision support tools (to assess the design strategies), a very effective logistics (able to optimize the resource recovering at the building end of life), and a legislative action (able to support clients and operators).

The construction sector has a large environmental impact, due to its energy and materials demand, along with a high production of waste. Construction waste produces over 40% of the total waste in the European Union. In 1997 a study estimated that 20 million tons per year are produced by construction and demolition (C&D) activities in Italy, with 90% of this amount from micro demolition and maintenance activities and only 8% of the total amount from entire building demolition [Celino, 2000].

Other estimates raise the total amount of C&D waste in Italy to 45,9 million of tons/year [Apat, 2007], and confirms the very fragmented origin of the majority of this flow, as well as the low rate of C&D waste recovery (less than 9% of reuse and recycling, compared with 28% in the EU as a whole).

To close the loop, we must make a feasible and easy reverse construction process, coupled with very effective networks for the exchange of salvaged resources. The first target needs to include, in the design process, the planning and optimisation of the buildings entire lifecycle in order to maximise the resources future reuse and recycling. According to Yeang "The design might regard the creation of a built form as a form of energy and materials management". It means that the designer is ethically responsible for the designed system over its entire life cycle up to its "after life, so he must be concerned with how the designed system and all its component can be taken apart or disassembled in ways that will allow maximum levels of reuse and recycling" [Yeang, 2006].

In this framework, we now define as "reversible design," is a design process that also systematically plans the decommissioning phase of any building element, in order to allow that, when deconstructed or disassembled, it can be easily removed and then reused or recycled.

The best effects of this approach are especially expected in maintenance, rehabilitations and adaptations activities, where a well-planned dismantling procedure prevents makeshift solutions and helps the C&D waste diversion from landfills to an effective valorisation.
The feasibility of such eco-friendly strategies in the Italian construction sector still remain controversial, because of both the requested level of technical specifications - higher up the current professional practice - and the underestimation of the costs related to the environmental impacts.
The research has identified a couple of strategies as being more effective in bypassing the main barriers in this process:

a. Establishing and Organizing Current Knowledge: a good library of technical information on deconstruction recycle/reuse chains of building materials and components can feed a virtuous retroaction from the design phase. On this basis, the threshold of reversible design can move from intentions to actual practice, making effective the switch from non reversible to reversible at any scale of the building design;

b. Developing Performance decision support tools: a reliable prediction of the effects that result from the application of an eco-design strategy should motivate designers and clients to adopt innovative solutions and technical options that will drive to the smart use of resources along their lifetime.

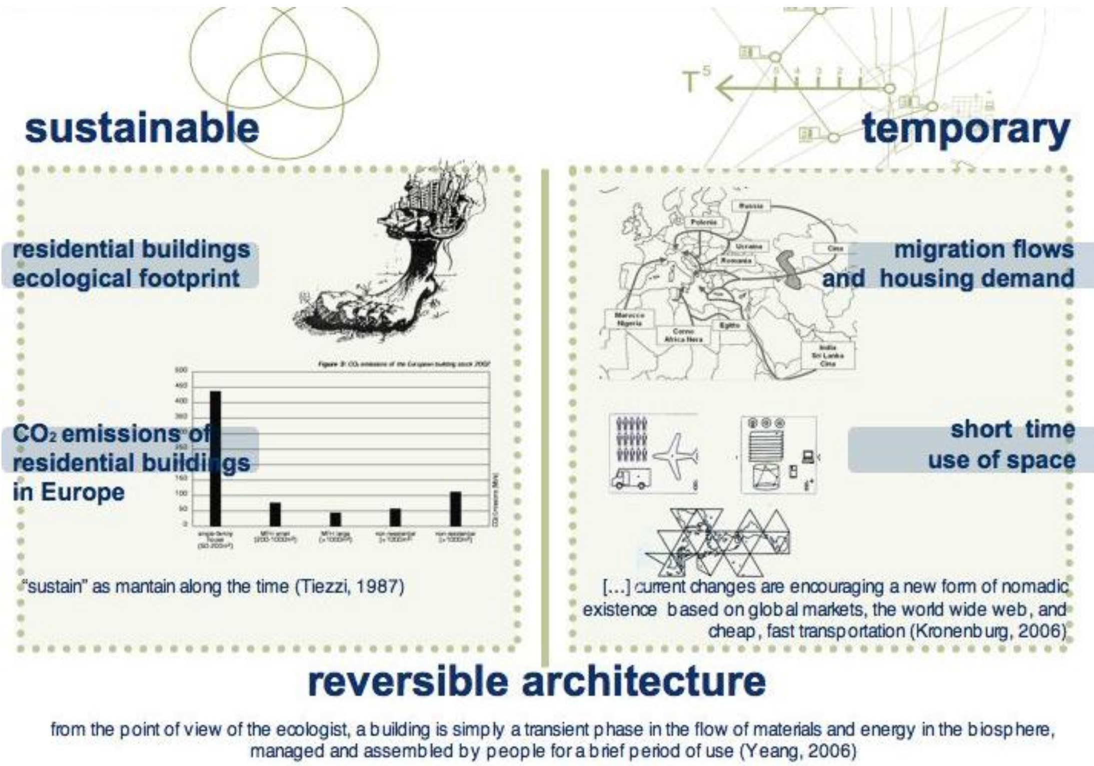

Fig. 1. Starting point of the research

RESIDENTIAL CONTEMPORARY CONTEXT

The research investigated the dynamic of social needs in the Italian housing sector: it identified a set of trends, which act as drivers in the demand for living spaces that are changing and can be flexible by using short term modification of these living spaces.

The pressure to change and adapt is intense in the current building stock in new residential buildings market. The environmental impact of this pressure requires urgent measures. Although is not the exclusively responsible, it does contribute significantly to the increase of the ecological footprint of the Italian housing, as it is currently estimated at 0,07 global ha/person including construction and maintenance activities, compared with a global national footprint of 3,8 global ha/person [WWF Living Planet, 2004].

Despite this, the current supply of building stock is far lower than that needed to fill the needs: the housing demand is increasing, as pointed out by some recent studies that estimate that 400,000 dwellings are needed to supply the current demand for primary housing (the demand was 173,000 dwellings in 1991). Moreover, the increasing housing demand mostly comes from new social actors: elder people, students, singles and legal immigrants with their families (increased from 1.5 to 2.5 million between 2001 and 2004) [Cresme, 2005].

The old existing residential buildings often represent the only affordable response for this demand, and this increases the needs of adaptation of this stock to new requirements, with a subsequent large amount of refurbishment activities, that are split in a flurry of micro-works.

TOOLS TO ASSESS END-OF-LIFE SCENARIOS FOR BUILDINGS

Various tools have been developed to establish an eco-friendly end-of-life scenarios for buildings, with different goals for each: the management of demolition or deconstruction project (Deconstruction Planning System, DFIU, Germany-France); the environmental and economical assessment of end-of-life scenarios (Building End-of-life cycle Analysis Tool, TU/d, Holland); the cost/benefits estimation of reuse and recycle in relationship with embodied energy in materials (Method for Assessment of the ease of disassembly of building constructions, Lund Institute of Technology, Sweden) and to assess the feasibility of a deconstruction project (Building Deconstruction Assessment Tool, Centre for Construction and Environment, Florida).

A second group of tools aim at supporting operators in the decommissioning process and in the management of waste flows. Some of these propose a method to assess the potentiality of a building system to be disassembled by measuring the environmental performance of this operation, like Deco (IUAV, Italy). Many and various are “material exchange” platforms especially dedicated to the building sector, offering an infrastructure to facilitate the recovery and reuse of salvaged materials coming from building deconstruction, like VAMP, (EU Life, Italy).

The two Italian tools were particularly investigated in relationship with the research goals.
The VAMP tool was developed from 1998-2000 by Emilia Romagna local government, within the framework of a project funded by the EU LIFE Environment Programme, which supported an experimental application of the VAMP tool in the Northern Italy cities of Modena and Reggio Emilia. This tool works by supporting operators in finding salvaged building materials and components.

Focused on this purpose, VAMP is a web-based information system that manages and links the C&D waste supply with the demand recorded in a specific area. It is accessible by Internet to all users wishing to hand over the waste produced by C&D activities or interested in obtaining waste for re-use in C&D activities. The system offers a support to direct the flows of waste materials in the most sustainable way and to help building firms to form a disassembly/deconstruction plan.

In 2005, the Provincia di Torino - the Authority in charge for the control of the waste management activities in Turin area - decided to adopt the VAMP system by adapting the tool to the local requirements. After some tests, a revised version of VAMP is now operational in the Turin area since late 2006.
The Deco tool is developed by IUAV, Venezia, in the framework of a MURST 2000 PRIN research programme (coordinators Prof. Sinopoli N. and Prof. Mucelli G.), for assessment of

technical solutions potentiality to be disassembled to salvage materials.

Deco analyzes the technical configuration of each building element, to evaluate its potentiality to preserve, where disassembled, the maximum integrity of its constituents materials and components. Deco defines the integrity by two combined indicators. The first one measures the option of maintaining the original physical, geometrical, and dimensional qualities of each building element constituent after its disassembly. This indicator is called "wholeness" and is strictly related with the potential reuse of the building elements. The second indicator, called "homogeneousness", is based on the chemical purity of each disassembled constituent of the building element and is strictly related to the recycling potential.

Starting from the analysis of the layers of selected technical solutions and the type of connection between two adjacent layers, the tool allows the assessment of the intrinsic level of reversibility of the assembled building element (from very bad to very good level) and the quantification of the salvaged materials and the ability to be reused or recycled.

Case Studies Assessed with the Deco Tool

Aiming to establish a critical evaluation of the tool features, this research carried out a test of Deco by its application on selected case studies.

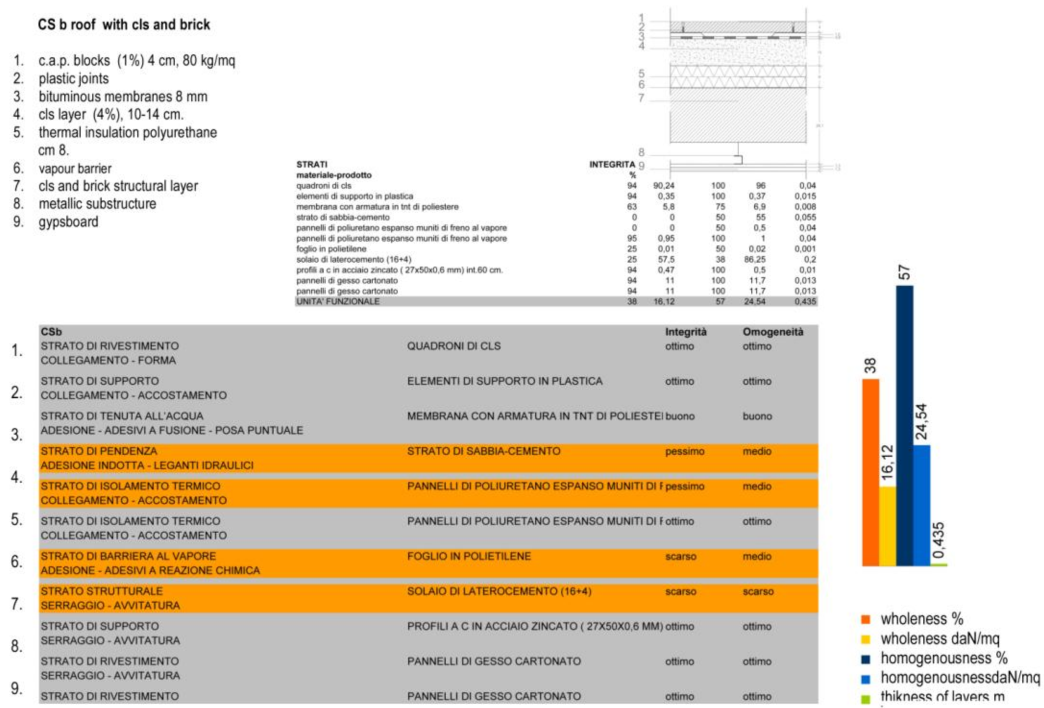

Fig. 2. Case Study Assessment

Technical configurations for the walls and roofs of seven selected residential case studies were assessed to estimate their disassembling potentiality, by calculating the quantity of constituent materials able to be potentially reused (through the "wholeness" indicator) or recycled (through the “homogeneousness” indicator).

The seven case studies cover a large palette of building techniques, spanning from very traditional (e.g. concrete and masonry) to modern methods of construction (e.g. prefabricated volumetric units and panels). In particular, the selected construction methods were: on site concrete frame structures with masonry walls; structural masonry; steel frame and panels; wood frame with prefabricated composite panels; steel and wood frame with mechanical connected layers; steel volumetric units; and steel frame and composite panels.

The comparison of the results obtained by Deco application on the case studies indicate that the level of reversibility of an assembled building element depends essentially from the characteristics of the system used to connect its constituents parts [Mucelli, 2004]. The test also highlights that the information resulting from Deco through the “wholeness” and the “homogeneousness” indicators make it possible to define the total amount of material potentially recovered, therefore able to be diverted from landfill. In addition, the test confirmed that Deco could also be used as a simulator during the design phase of a building, allowing for the optimization of the designed configuration through the prediction of its ease of future disassembly. It suggests the correction of some design decisions about layers and connections, in order to obtain the maximum salvageable materials.

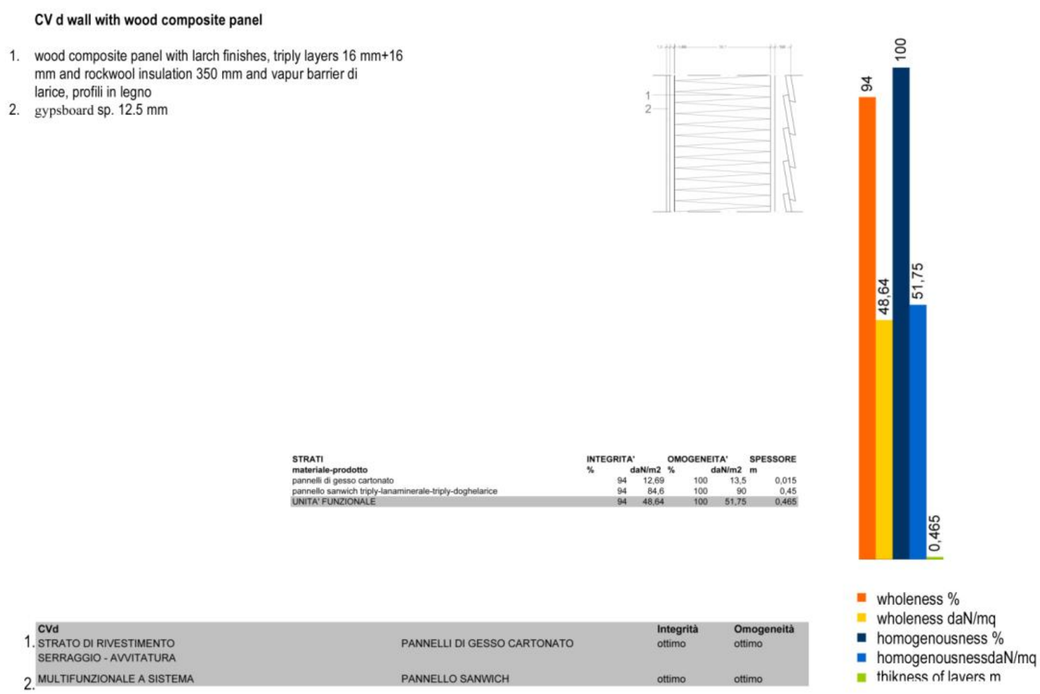

Fig. 3. Case study assessment

The most common optimization suggested by the Deco application concerns the replacement of connections made by techniques or materials that are difficult to separate such as waterproofing bituminous membranes, concrete on site layers, brick connected by mortar and in general any “wet joined” assembly.
The size of the element as well as the thickness of the layer only marginally influences its ease of disassembly. In prefabricated systems, the glued layers of big composite panels shows

the same low potentiality to be disassembled, as do small bricks connected by mortar.
In reverse, any “dry connection” - in which the cohesion between layers is secured by mechanical reversible joints - offers a high attitude to be easy disassembled, with a subsequent big potential of constituents recovery.

Suggestions for reversible design of technical solution

Some suggestions have been gathered from the analysis of the critical connections between layers, in order to avoid the less effective solutions. This research doesn’t aim at establishing a catalogue of “best technical configurations”, but to demonstrate that in many cases, a better solution can be performed that produces only a few alterations of the architectural character, but dramatically increases the reuse and recycling of building materials as well as easier maintenance and repair.

For this purpose, the technical configuration issued from the cases studies has been re-designed, to compare the alternative solution by evaluating their attitude to be disassembled through the Deco method. To make the simulation more realistic, further information has been added providing detailed technical specifications about the suggested alternative materials. In addition, the recycling plants and the salvaged material exchange facilities have been identified and a search engine of where to find them has been developed. Making realistic suggestions on technical solution improvement could demonstrate the margin of amelioration that still exist in this field and the potential benefits that could be obtained both in effectiveness of maintenance and repairing activities and in reduction of C&D waste production.

As maintenance and repairing activities in small buildings are one of the main causes of C&D waste production in Italy, designing technical solutions by keeping in mind the disassembly and salvage, can reduce the environmental impact of building activity and the maintenance and repairing costs for ease of replacing or reducing. This suggests that ecological strategies and eco-design could converge designers and builders, joined to exploit the great potentials of an intelligent use of resources for all of the buildings lifetime.

Thresholds of reversible design

As the methods of construction originally adopted emerge as the key factor in order to allow the reverse construction process, the “thresholds of reversible design” have been defined, intended as the optimization of the potential of a building element to be disassembled at the end of its planned lifespan, with the minimum need of resources and the maximum output of salvageable materials.

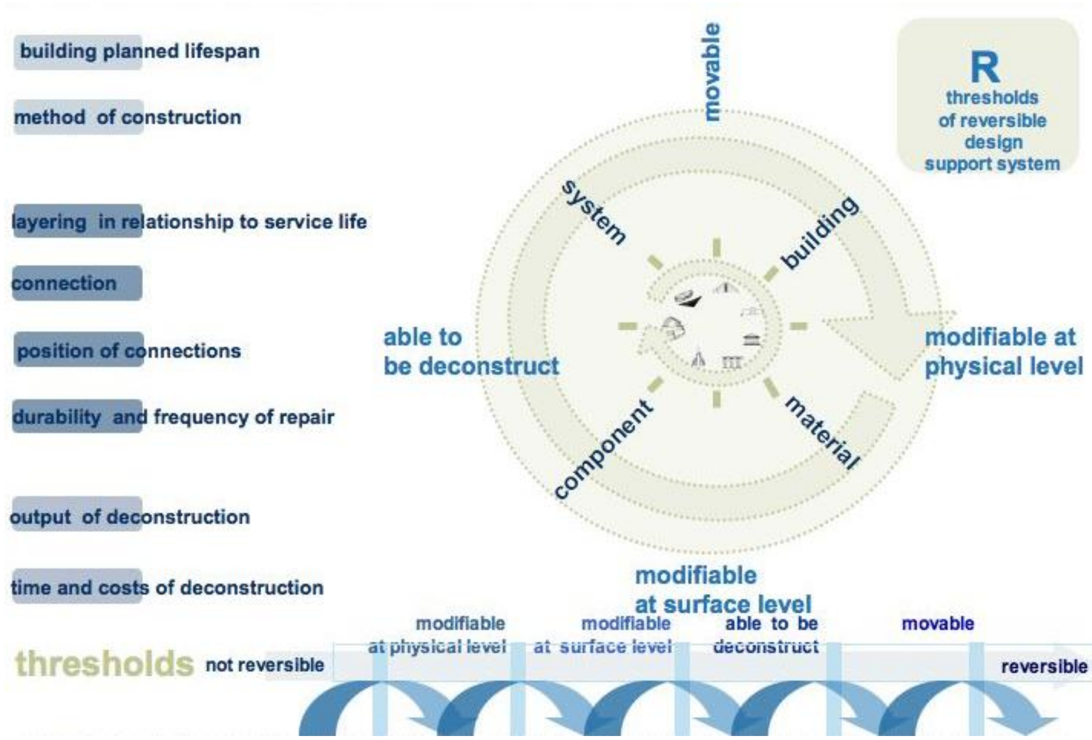

Fig. 4. Scheme of reversible design support system

In the proposed system, the range from a non reversible to a reversible building configuration is modulated on four thresholds and identified by two indicators: the quantity of salvageable resources and the "depth" of the level that the disassembling process can easily reach.
The shallow level is the positional one. It is reached when the disassembling action can only reallocate some layers or elements of the original configuration, without any further modification. The second threshold is reached when the disassembling can operate on the surface level of the component, by removing or replacing it. The third one identifies a configuration in which entire components can be disassembled preserving its wholeness. The highest threshold concerns the whole building.

Based on the thresholds, a classification of the disassembling strategies could be established in order to optimise the design phase and to finalize it to the achievement of the best eco-friendly buildings end-of-life. From the investigation of existent tools emerges the consideration to also implement qualitative tools to support designers and builders in their daily work and to promote eco-design in a life cycle thinking view by considering and planning the lifespan of the designed system. Goal of the matrix is to identify the key factors and related needed information to suggest eco-design strategies and qualitative inputs to make real reversible design.

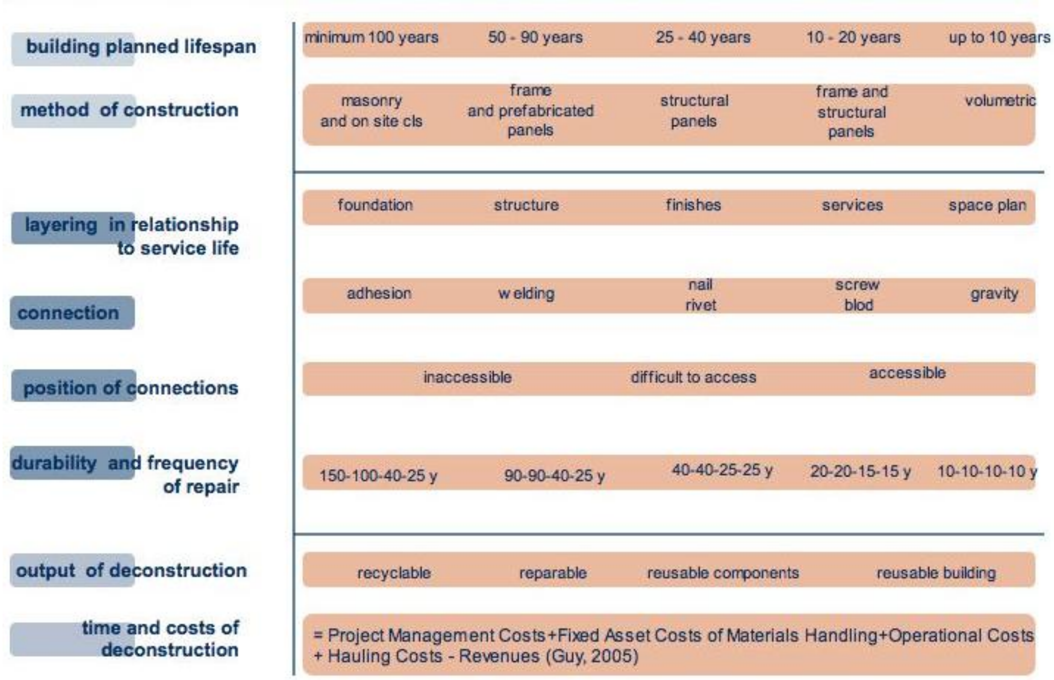

Fig. 5. Matrix of reversible design support system

SECOND LIFE OF MATERIALS AND COMPONENTS: THE NETWORKS OF SALVAGING OPERATORS IN ITALY

The easy access to an effective network of salvaged materials exchange platforms and recycling plants is crucial to make a feasible, large-scale adoption of environmentally friendly building deconstruction practices. To allow the users to use or access the network, it must be supported by an effective information system that is able to identify and localize the existent flows of salvaged materials, as shown by several experiences worldwide [Antonini, 2001].

In the framework of this research, a web blog has been launched to provide an information exchange platform on salvaged building materials. The blog collects and makes known data about recycling facilities active in Lombardia (Northern Italy region) and is also based on the National Register of Recycling Operators and Local Authority waste control office data.
This tool aims to facilitate the management of the waste flow coming from C&D activities and to promote the reuse of salvaged building materials and components by designers and builders.

The survey shows that the reuse chain still remains largely ineffective in Italy and the recycling and reuse practices are very discontinuous as well as the flows of salvaged materials and components. But, it also shows that the recovery of reusable fractions of C&D waste have a great potential and can implement a larger market able to involve a larger number of players, from developers to designers, to construction, maintenance, and demolition firms as well as various charitable associations and "border line" people interesting in exploiting the flows of second life components and materials.

CONCLUSIONS

Only whole life cycle thinking makes possible an ecological use of resources, especially in buildings, in which the role of the design emerges as a crucial factor for the success of sustainable practices. The lessons learned from the good examples of environmentally friendly effective disassembling and C&D management also concerns the role of a good information system supporting the waste flows management and second life materials use, as well as the availability of performance decision support tools easy accessible by architects and builders in order to optimize the disassembling strategies to adopt.

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