Reducing and reusing industrial scraps: a proposed method for industrial designers

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1. Introduction

In this research we combine the fields of industrial wastes production with product design, assuming that there are great economic and environmental potentials (Plouffe S. et al., 2011; Borchardt M. et al., 2011) in designing products by adopting sustainable design practices such as reusing industrial wastes and, more in detail, scraps. Ecodesign processes have been analyzed and developed in order to define the best operative strategies and the tools needed to assess products' environmental requirements (Pigosso D.C.A. et al., 2009; Bovea M.D., Perez-Belis V., 2012). Our research consists in a new design method focused on minimizing and reusing industrial scraps in order to obtain serial products who can lead to economic and environmental advantages for the company. Interactions between industrial designers and engi-neers sometimes are difficult to achieve, and some ecodesign strategies were developed in order to solve this problem (Rio et al., 2012). Our research consists in a design driven application whose aim is to understand the feasibility of developing products based on waste reuse. In order to define all the procedural steps of the used method, we start from analyzing several manufacturing processes and wastes related to them (Thompson, 2007), defining potentialities and limits of each technology here presented. Parallel to these technological considerations we present design case studies based on waste reuse, demonstrating on one side that the interest of international design research related to this topic is growing, but on the other side that the usual industrial designers' approach related to waste reuse is often unstructured and unrepeatable. Especially this last point evidences, the need of this method to outline a design driven approach able to support the product development phases in order to design components and parts with a coherent approach from an industrial point of view.

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The three procedural steps of our methodology represent a useful model for designers to organize concepts and design proposals based on industrial scrap reuse in a structured and simple way, in order to better understand which is the most preferable solution to follow.

2. Industrial wastes and scraps

2.1. Italian legislation

Waste production and management are themes of great interest for Italy due to the large amount of companies, capitals and resources involved in industrial processes, even if sustainable oriented practices and methods such as LCA started to being applied in the country just in recent years (Tarantini et al., 2009). Italian legislation in the past fifteen years has been very active in structuring norms designed to change the approach to industrial wastes' treatment, managing them in a more sustainable way for the environment. The 2006 Legislative Decree (Dlgs)152/06 defined a more structured approach to sustainable wastes' management, introducing tools such as the Strategic Environmental Assessment (VAS) and Environmental Impact Assessment (VIA). In 2008, European Parliament approved the 2008/98/CE directive, defining a hierarchical order for wastes' management and handling, establishing as prior design operations their prevention and preparation for reuse, followed by recycling and energy recovering activities, considering landfill disposal as last preferable above all. The 2008/98/CE was received in Italy in 2010 with Dlgs. 205/10, which introduced in the national legislation the hierarchical prevention order disposed by the European directive with the active participation of Sistri, a service born to facilitate wastes' traceability and monitoring.

2.2. Wastes' production and management

According to the Dlgs 205/10, urban and special wastes consist in material produced by someone who needs or has to discard it. While urban wastes come from domestic and public areas, special wastes are generated by private sectors such as agriculture, industry, handicraft or waste treatment plants. We focus this research on special wastes production. In 2011 the ISPRA Institute published the Special Wastes Report, a document which analyzes data and statistics on wastes' production and management in Italy. The report shows how in 2009 there was a deflection in wastes pro-duction compared to 2008, for a total of 128.5 millions tons. The manufacturing processes generated a large amount of wastes, for a total of nearly 36 millions tons, equal to 28% of overall production. Registered data related to waste management in 2009 showed how recovery and recycling operations represented in Italy the most practiced choice, involving 77.7 millions tons of material, equal to 67.7% of the overall special waste production. While this is an encouraging statistics, there were still 13 millions tons of special wastes landfilled, equal to an overall 11.3%.

2.3. Design strategies for product optimization and waste reduction

A big role in reducing and optimizing the use or resources and energy is represented by simplicity. We present how it has been approached in past and contemporary industrial design history (Maeda, 2006). Design for Assembly (Boothroyd and Alting, 1992), Design for Disassembly (Crowther, 1999) and Design for Environment (Billatos and Basaly, 1997) are practices aimed to facilitate factory assembling operations and end-of-life products' recovery. Whole System Design (Stasinopoulos et al., 2008) and Whole System Engineering (Pahl et al., 2007) define a different approach to design, focusing on the entire product-system optimization instead of simply considering single components or single assemblies. This olistic approach needs to be adopted since the earliest phases of product development, also highlighted by Front Ended Design (Blanchard and Fabrycky, 2006). Lean Manufacturing (Sugimori et al., 1977) is an industrial management strategy conceived to improve internal logistical organization of material and worker fluxes in order to reduce energy and time wastes, focusing on the real perception of value for the customer. Mainly developed to solve or reduce environmental issues caused by industries, Design for Environment (Giudice et al., 2006) and Life Cycle Assessment (Curan, 2012) are practices whose aim is to define valuable strategies to reduce harmful impacts related to an industrial production after analyzing and evaluating all the phases of a product life cycle. All of these strategies need to be planned from the earliest moments of the definition of the concept design, since at this step the 80% of the production phase costs are already set (Anderson, 2008), and design changes adopted on the subsequent phases might become really unproductive for a company.

We present also some of the recent scientific studies which demonstrate the potential economical and environmental advantages achievable from practices such as reuse, recycling and remanufacturing. Chongqing Technology and Business University developed a redesign methodology (Du et al., 2012) based on an axiomatic design theory which demonstrates how designing remanufacturing strategies for product refurbishing could lead to significant results. Refurbished components have to maintain the same original functions and can't be modified too much, but through strategic and well-designed remanufacturing operations it is possible to obtain the same original performances even in complex machines such as an industrial lathe.

A work by Castro-Gomes J.P. et al., 2011 (Castro-Gomes et al., 2011) presents the potentiality of reusing wastes derived from mining and quarrying activities in order to realize polymer-based composite materials for artistic and mechanical products instead of traditional landfill disposal. Ceramic wastes could be used to obtain new concrete formulas improving mechanical and durability performances compared to traditional ones (Pacheco-Torgal and Jalali, 2009).

Reusing industrial wastes in processes such as vitrification allows the reuse of industrial hazardous wastes in order to obtain inert glass-based products such as fibers, foams, nucleation and sinter-crystallization glass-ceramics (Colombo et al., 2003). Another significant application for hazardous wastes is constituted by their use as reinforcing fillers in polypropylene composites, obtaining different mechanical and technical performances depending on the type of processing typology applied to the waste itself (Zheng et al., 2008).

The management of more structured end-of-life scenarios and industrial waste reuse could lead to several advantages in terms of environmental sustainability and many national and international researches (mainly based on LCA method) have been conducted related to this aspect (Glew D. et al., 2012; Vermeulen I. et al., 2012; Tsai W.T., Chou Y.H., 2003).

3. A proposed method for industrial designers

3.1. Scraps, rejects and reuse

Industrial wastes are produced by many manufacturing sectors involving different materials and technologies. Wastes can be defined also as the non-value results of a manufacturing process set up to realize specific components. They can mainly be divided in two typologies: scraps and rejects.

Scrap is a kind of waste predictable since the design and process definition phases. Quantities, masses and volumes involved in scrap production are exactly that can be predicted in these early phases since they are strictly bonded to a manufacturing process. The production of scraps and designed components are directly pro-portional, and after each manufacturing cycle scraps present serial characteristics. Scraps' production can be minimized but it is often not avoidable due to technical, materials or manufacturing con-straints and product and process engineering have a fundamental role in the optimization phase.

Rejects instead are defective components not compliant with design specifications due for example to geometrical and dimensional tolerances or wrong machineries set-up. Rejects cannot proceed to the next production chain steps unless refurbished. The ideal production of rejects should be tending to zero (Gitlow, 2000). This kind of industrial wastes is just statistically predictable since they are caused by many external factors which make them not serial and highly variable.

In Fig. 1 a schematization of wastes derived from a blanking process is presented to visually identify the differences listed above. Both scraps and rejects are produced by forming processes, but for their characteristics (especially seriality and predictability) we find that scraps are much more interesting in terms of their reuse for industrial design applications. We based our research on industrial scraps.

In the life cycle of a product the methodology finds a collocation after the phase of design and process definition related to a specific component (Fig. 2). The reuse principle corresponds to one of the first steps to consider for waste management according to National Legislation and European Directives.

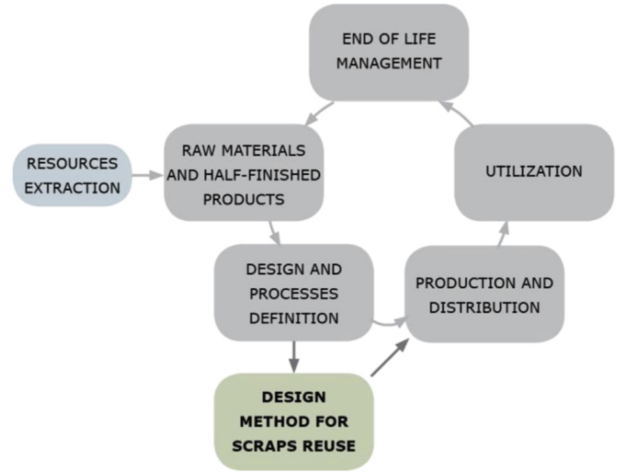


Fig. 2. Collocation of the design methodology in product's life cycle.

3.2. *A new method for product designers*

The methodology presented in this work aims to become an instrument for designers to develop products based on scrap reuse. In particular this approach is intended for designers to evaluate if the operation is economically and environmentally advantageous compared to the realization of the same product using new raw materials or new half-finished components adopting standard industrial procedures. Our methodology is constituted by three main sequential steps, which we define as:

Phase 1 - Scrap optimization.

Phase 2 - Unavoidable scrap analysis.

Phase 3 - Designing with scraps.

Phase 1 - Scrap optimization involves the design definition phase related to manufacturing a specific component since the related scrap production is predictable and quantifiable. Product and process engineering affect this phase of the method, which can be applied when scrap production can be predict and exactly quantified. In order to optimize and reduce scrap production, we identify two aspects as most influential, namely geometrical and formal parameters.

Geometrical parameters are divided in two points. The first one consists in adapting the dimensions of the components to half-finished products' area (such as in nesting operations) or vice-versa, which means designing and producing customized half-finished products based on components' dimensions, optimizing their disposition on the available area with the purpose of reducing scrap's production and incrementing process' efficiency; the second point consists instead in refining and adjusting components' design for those industrial cases where raw materials (and not half-finished products) are used in a specific manufacturing process, in order to optimize the use of resources and to reduce scraps production.

Formal parameters instead are related to a general simplification of the designed component related to a manufacturing process and consequently of the overall product architecture, focusing on the real perceived value by the client, avoiding what is unnecessary. In most of the industrial scenarios it is not possible to totally avoid scrap's production even after the application of the described operations. We called the remaining scrap production derived from a specific manufacturing process "unavoidable scrap", which has to be analyzed in the next step of the method before approaching the potential design phase. In Fig. 3 we propose a flowchart schematization of Phase 1.

Phase 2 - The unavoidable scrap analysis consists in the formulation of a list of the characteristics of the unavoidable scrap with the scope of highlighting both qualities and limits of the potential reuse applications for the next design step of the methodology. In order to set this list of scrap characteristics and

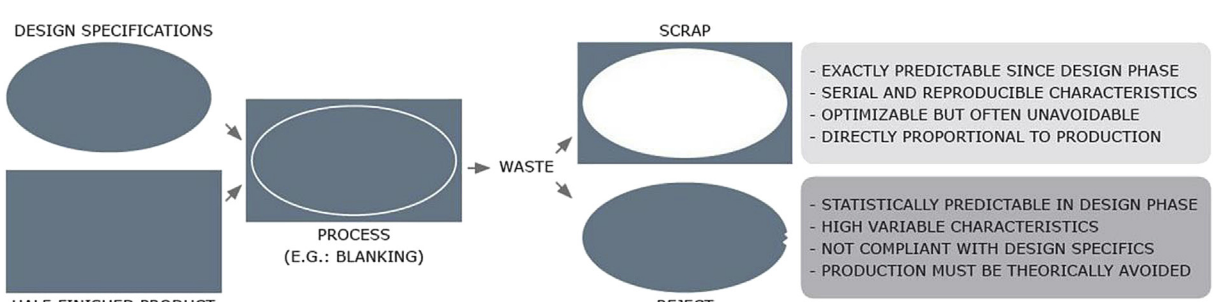


Fig. 1. Example of scrap and reject production derived from a blanking process.

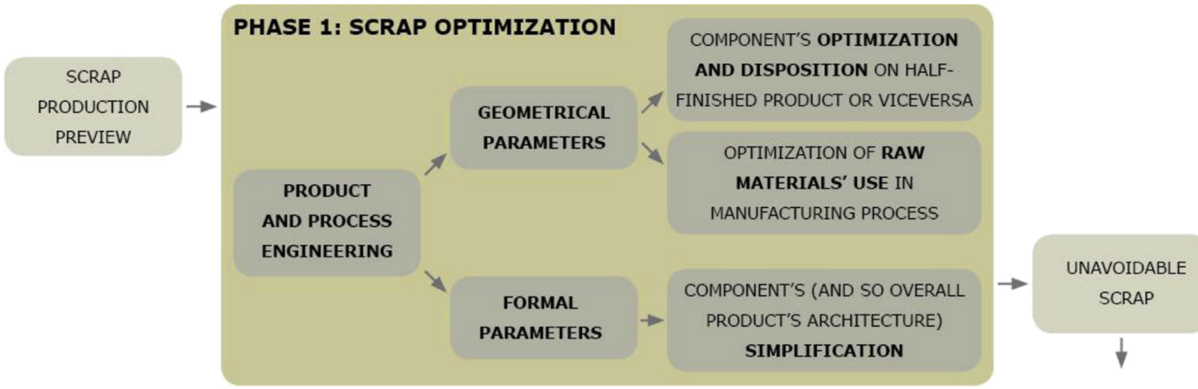


Fig. 3. Flowchart of Phase 1/Scrap Optimization.

define the potential of waste reuse, we identify six main categories:

Productive analysis, which involves aspects mainly related to the industrial process adopted in factory. In this moment the manufacturing process related to scrap production, their total quantities in terms of volumes and masses produced in a defined period and how scraps are typically managed by a company need to be defined.

Functional analysis, which helps in defining those qualitative and general formal aspects of a single scrap unit (or of the overall volume produced in case of swarfs) useful to stimulate ideas based on the possibility of reuse it for some other product applications. Designers must consider the overall scrap shape, surfaces, how they define the shape of a component (and if they are regulars or not) walls, details, cavities, edges and ends and eventual irregularities which may compromise its potential reuse.

Dimensional analysis is based on the quantitative definition (by a geometrical point of view) of the single scrap unit. It has to be set by conducting some measurements such as volumetric sizes (length, depth, height) and establishing if there is some variability among the scraps, due for example to particular dimensional tolerances. Another relevant aspect is the measurement of the scrap section involved in loads resistance in order to prevent critical breaking points in potential reuse applications.

Mechanical analysis, which has been thought to define a list of scrap specific properties related to the material, such as for example Young's modulus, shear modulus, yield strength, compressive strengths. The relevance of a specific property on another may be different depending on the cases. The other point related to the mechanical analysis consists in establishing the scrap potential processability or machinability, in order to define design opportunities but also technical limits of its reuse.

Physical analysis is related to all of those characteristics typical of the specific scrap material, such as: thermal properties (maximum and minimum service temperature, thermal conductivity, thermal expansion coefficient), electrical properties (resistivity or electrical conductivity, dielectric constant), durability properties (oxidazibility, resistance to acids and alkali and to corrosion, flammability, photochemical degradation), optical properties (refraction index and transparency), magnetic properties (permeability and polarizability), environmental properties (toxicity, biodegradability, recyclability and embodied energy related to recycling, availability of natural resources and raw materials).

3 *Sensorial analysis* involves tactile, visual and olfactory aspects Phase 2 is the second basic step of the method, which helps in defining a list of the relevant characteristics and properties of the scrap for the potential next design phase. Fig. 4 presents a flowchart schematization of Phase 2.

Phase 3 - Designing with scraps represents the last of the three main steps of the method. This is probably the most articulated part, since its aim is to establish if the design operation based on scrap reuse is valid or not. However, before starting the design phase, we identify two supporting instruments called Preparatory

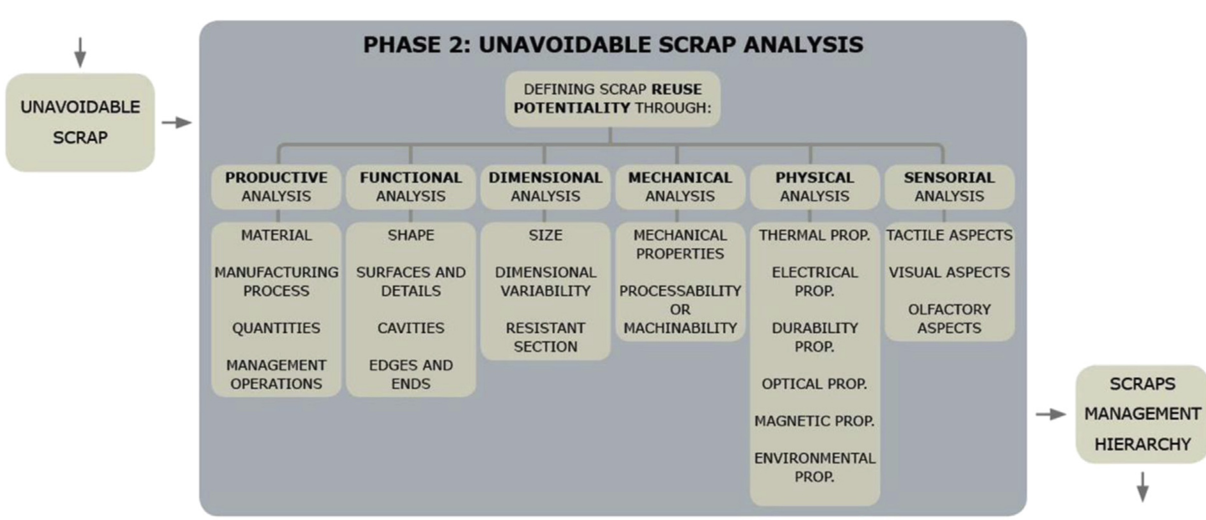


Fig. 4. Flowchart of Phase 2/Unavoidable scrap analysis.

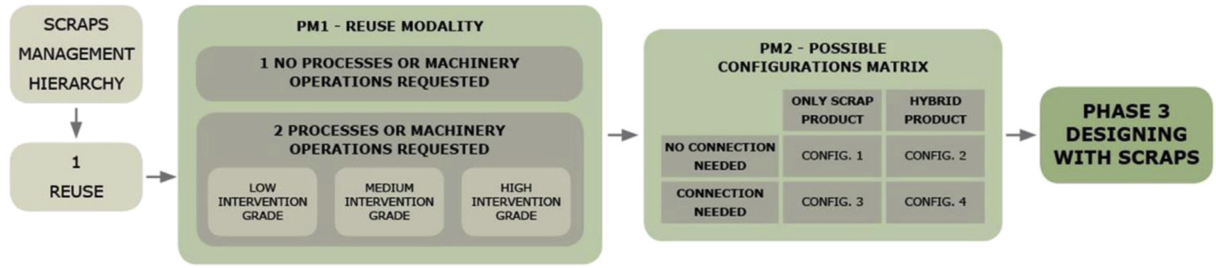


Fig. 5. Flowchart of Preparatory Moment 1 and Preparatory Moment 2.

Moment 1 and Preparatory Moment 2, whose scope is to help designers in generating a mental scheme of what it is possible to do with scraps in a structured way. These two moments do not constitute effective operations on the scraps, but they are useful to the subsequent concept design phase.

Preparatory Moment 1 (PM1) refers to the methodology for scrap reuse, defining if processing or machining operations on scraps are needed and how they can be conducted.

Preparatory Moment 2 (PM2) is related instead to potential product architecture configuration, that can be structured with the support of a matrix that we developed. In this 2x2 matrix, columns identify the type of components of a product based on reuse, which can be constituted just by scraps (first column) or combining scraps and new designed components (or anyway components or material that are not waste) in order to achieve the final product architecture (hybrid product, second column). Rows instead are related to the necessity for the components of a product to be connected or not, involving all of the possible industrial connection modalities. It is relevant to underline the industrial aspect of the reuse operation, in order to avoid artistic-handicraft product concepts which are not the reason the method is designed for.

PM1 and PM2 (whose flowcharts are presented in Fig. 5) are two introductive tools to the real design phase and aim to help the designers in defining it in a more organized and structured way.

The real operative step of Phase 3 (whose schematization is proposed in Fig. 6) is the design definition phase, which aims to develop an idea for a product based on scrap reuse establishing if it makes sense or not. We divide this moment of the method in two main blocks. The left block presents product development procedural steps (Ashby et al., 2007), starting from the definition of a concept. In this first step there are several design scenarios and the designer has to start combining and visualizing potential applications of reusing scraps according to his skills and experience. There is a substantial difference between a new product development and the development of a product based on scraps reuse. While in the first case the definition of an original product concept starts from a “zero condition” where each component, material and process has to be defined, in the second case (corresponding to our condition) the ideation of a product concept presents much more constraints derived from unavoidable scrap's characteristics and properties, which are set and have been already defined previously in Phase 2, constituting the base of product architecture: a product concept based on scrap reuse can not be regardless of this relevant aspect. One evident design implication corresponds to the fact that it is not possible to develop concept proposals just based on a market research as it happens instead for new product concepts, but it would be also senseless to visualize a concept idea for a product not based on a market demand. In order to solve this problem (and to avoid a messy approach to design), we define a possible strategy to develop both product architecture based on scrap reuse and market research in order to validate the concept proposal. It is useful to consider three aspects: a) does the product respond to a precise function related to a market demand?; b) are there on the market existing products with characteristics and properties comparable to the concept design proposal?; according to a preliminary evaluation, does the product development make sense on an industrial-scale production? If the answers to these three qualitative questions are affirmative, the concept idea can

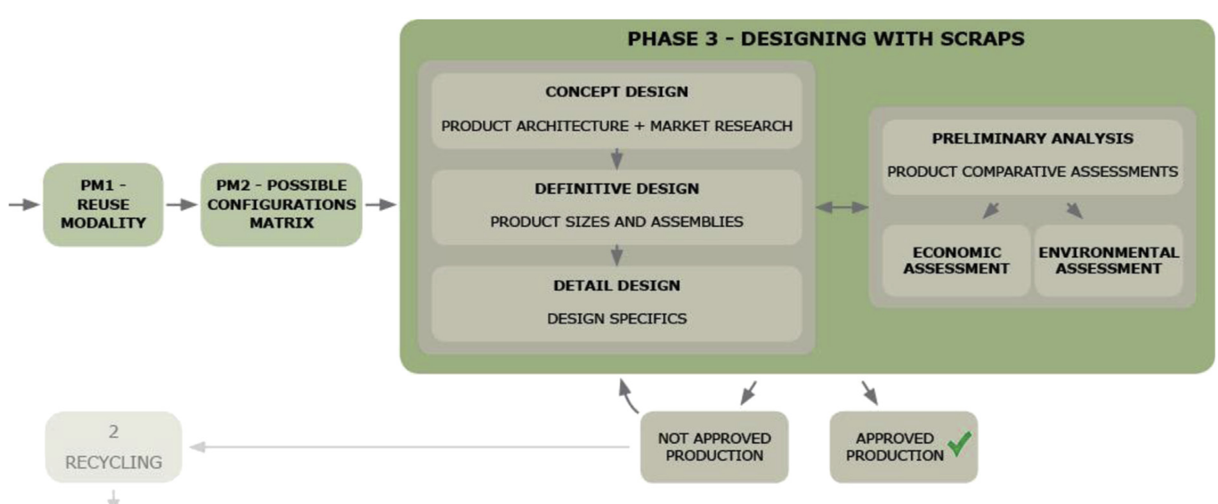


Fig. 6. Flowchart of Phase 3/Designing with scraps.

proceed on the next step of product development, which is definitive design. In this procedural step concept aspects such as single component sizes and processes have to be defined with more depth, in order to achieve a defined product architecture. The next step is detail design, which consists in a process of refining, adjusting and optimizing all the aspects of a product in order to establish design specifics, or rather all of that information necessary to a company for the realization of a product.

Through design specifics it is possible to move to the prototyping phase, where it is physically possible to conduct tests and modify design details if necessary until the design specifics are set as final and the production could theoretically start. However, before starting an industrial production, it is important to conduct both economical and environmental assessments in order to validate the reuse operation from an industrial point of view. We define this basic operation (the right block in Fig. 6) Preliminary Analysis, which has to be conducted and progressively corrected in parallel with product development from concept to detail design phase. The assessments are based on comparing the product based on scrap reuse with the same product as if it would be realized as a new product starting with new raw materials or half finished products. Economical assessment involves mainly the establishment of the single units and the batch production costs, while environmental assessment can be conducted by comparing the life cycle of the two products (by a LCA procedure for example) in order to define en-ergy and environmental emissions related to the reuse operations. Another interesting point to consider is to evaluate both econom-ical and environmental advantages derived from the operation compared to traditional scrap management by the company who produces the scraps.

At this point, three questions can be useful to designers and companies to proceed with the work: a) does the product based on scrap reuse respond to a market demand accomplishing a precise function?; b) is it economically advantageous?; c) is it environmentally advantageous?; if one of the three answers is negative, it is necessary to return to Phase 3 and try to find and change those parameters that make the design proposal disadvantageous. If even after appropriate modifications the outcome is still negative, the design proposal based on scrap reuse is not advantageous and the second hierarchical operation to consider for scrap management is recycling. If all the three answers are positive instead, the scrap reuse proposal can be approved and it is possible to start the potential production phase.

4. Application of the proposed method

In order to test the validity of the procedural steps of the proposed method, we applied it to two original case studies based on waste production of two different Italian companies. Data and information have been provided by the companies. We apply the methodology also to six existing products related to six different materials and manufacturing processes, in order to demonstrate its applicability to different industrial scenarios.

4.1. Original case study 1: steelwork

The first case study consists in a steelwork company whose waste production (scraps and rejects) in 2011 corresponded to the 11% of the total mass of half-finished products worked. Different kinds of scraps and rejects emerged from the visit of the production area. Among them, we found interesting for a potential reuse design application some scraps derived from the automatic cutting process of standard steel pipes adopted by the company for the production of three components which constitute part of the metal frame of one of their products.

In this productive scenario, *Phase 1* (Scrap optimization) has been conducted by the R&D office of the company, which reduced pipe scrap production related to the cutting process intervening on geometrical parameters, precisely by optimizing and adapting the three dimensions of the components of the frame to the half-finished standard dimensions.

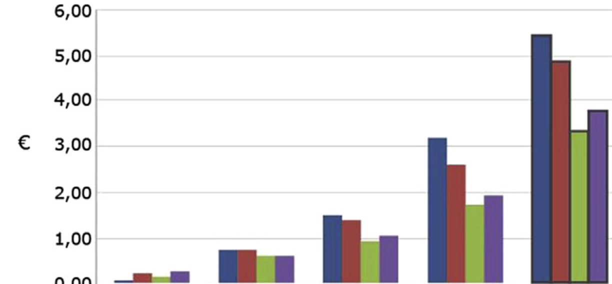
Phase 2. Unavoidable scrap analysis in this case represents the actual starting point for the application of the proposed method, as Phase 1 has been conducted by the production company. The information emerged through the productive, functional, dimensional, mechanical, physical and sensorial analysis of the pipe scrap points out a list of characteristics useful to evaluate the next design phase. The material of the pipe scrap is low carbon steel AISI 1020. A single scrap unit comes from the automatic cutting process of a 6000 mm standard pipe, obtaining a serial pipe scrap of 120 mm (diameter 20 mm, thickness 1.5 mm) for 82 g weight. The company produces approximately 100,000 scrap units per year, for a total production of 8.2 tons receiving 0.15 €/Kg for metal waste collecting by an external company. The pipe scrap has a circular prismatic form with a smooth external surface and some irregularities in the two edges due to the cutting process. Potential operations on the pipe scrap are notching, cutting, punching, welding, tapering. From a physical point of view, a very important aspect is constituted by durability properties, as with no external surface treatment the scrap is highly exposed to corrosion.

After structuring the list of the characteristics of pipe scrap, *Phase 3* (Designing with scraps) firstly starts by analyzing the potential reuse modality of the scrap (*Preparatory Moment 1*) and the probable product configurations (*Preparatory Moment 2*). These preliminary steps are followed by proposing some product concept ideas based on pipe scrap reuse. One of the ideas we find interesting to develop and comparable to other products on the market with the same function consists in a wall hanger. According to the procedural steps of the method, we moved from a starting generic concept idea up to the detail design moment, conducting the economical and environmental assessments in order to compare the hanger obtained by scrap reuse with the same product realized with traditional manufacturing procedures starting with new half-finished pipes. The hanger is constituted by some standard components (caps, plugs, screws and spacers) and a metal body made by pipe scraps derived from the cutting process. This version of the metal body of the hanger is obtained by reusing four scrap units which have to be cut, notched, punched, brazed and powder spray coated in order to obtain the final part for the assembly phase. We assess this first version of the hanger's metal body firstly defining manufacturing costs and then conducting a Life Cycle Assessment of the two solutions (metal body realized by reusing scraps or with traditional method). Manufacturing cost assessment points out how reusing pipe scraps in order to realize the hanger's metal body is less convenient than producing it in the traditional way (4.81 €/piece versus 5.37 €/p, for a difference of 0.56 €/p), since from an industrial and productive point of view, handling and processing the single scrap units compared to process half-finished products with a higher grade of automation affect the production rate time (16 p/h versus 19p/h). The economical assessment also highlights how relevant the processing and the energy and workers cost (directly influenced by production rate) are in determining the final cost of the component compared to money savings related to scrap material reuse. Conversely for the environmental assessment we compared the life cycle of the hanger as if it was realized in the traditional way with a second life cycle scenario which takes into consideration that from the scraps derived from the cutting process it is possible to obtain processable components in order to realize the hanger. Life Cycle Assessment conducted with Simapro 7.2 (Ecoinvent V2 Database) points out how the scraps reuse scenario for the production of the hanger's metal body is environmentally advantageous compared to realizing it with the traditional manufacturing procedures both for Global Warming Potential (0.4 Kg*CO_2eq versus 0.7 Kg*CO_2eq) and for Non renewable fossil resources extraction related to the production of half-finished components needed for the hanger's steel body (7 MJeq versus 11.9 MJeq). Starting from the results of the assessments of this first version of the hanger's metal body we develop a second version still based on scrap reuse. However, in this second version the hanger's metal body is constituted by 2 reused pipe scraps (avoiding processing such as notching, cutting and punching and using 4 MIG welding points instead of brazing) and 1 pipe realized in the traditional industrial way. Economic assessments for this second version points out how the hanger's metal body based on scrap reuse is advantageous compared to the traditional process based on new half-finished products (3.29 €/p versus 3.74 €/p, for a difference of 0.45 €/p). Life Cycle Assessment of the second version shows how the scrap reuse scenario is more environmentally sustainable compared to producing the same hanger's metal body in the traditional way (0.5 Kg*CO_2eq versus 0.8 Kg*CO_2eq for GWP and 9.3 MJeq versus 13.4 MJeq for Non renewable fossil resources extracted). However version 2A is found to be less environmentally sustainable than version 1A, due to the fact that less scrap material on version 2A is reused compared to version 1A (precisely 0.16 Kg for 2A and 0.23 Kg for 1A), defining a more impacting scenario according to life cycle assessment we conducted on Simapro 7.2 (Fig. 9). Both economic and environmental assessments of version 2A result anyhow valuable for a potential product industrialization compared to version 1A and 1B.

In Fig. 7 the two versions of the hanger's metal body are shown, with the coloured areas representing the reused pipe scraps. In Figs. 8 and 9 the results of the economical (Supplement 1) and environmental assessments are shown comparing the two versions (and so the 4 productive solutions). In these plots it is possible to see how the most convenient design from an economical point of view is represented by the 2-A version (due to the lower grade of processing intervention on pipe scraps), while the less environmentally impacting solution is represented by the 1-A version for both GWP and for Non renewable fossil resources extracted (due to the higher mass of scrap material reused).

4.2. *Original case study 2: polymer thermoforming*

The second original case study we present is related to scraps produced by a company which realizes vacuum thermoformed components starting from polymeric standard sheets. After visiting the production plant, we found interesting for a potential reuse application some scraps derived from the thermoforming and CNC milling of a component starting from a polymer sheet.



	Material cost	Dedicated cost	Processing cost	Energy and workers cost	TOTAL COST
1-A	0,03	0,71	1,46	3,16	5,37
1-B	0,20	0,71	1,35	2,56	4,81
2-A	0,12	0,58	0,90	1,69	3,29
2-B	0,24	0,58	1,01	1,91	3,74

Fig. 8. Economic assessment (the 4 solutions 1A, 1B, 2A, 2B) of the hanger's metal body.

Phase 1 (Scrap Optimization), as in the previous case, is conducted by R&D office of the company, which operates on geometrical parameters in order to adapt the dimensions of the component to a defined standard ABS sheet. This operation allows the company to obtain two components by a single thermoforming process. After CNC milling the two useful parts are separated from the scraps.

Through Phase 2 (Unavoidable scrap analysis) scraps characteristics are defined. The scrap is made of an amorphous thermoplastics (ABS), it weights 225 g for a production of approximately 1000p/y. The material is recyclable, so the company sells both scraps and rejects to an external company for 0.7 €/Kg. The dimensions of the scrap are $950 \times 100 \times 60$ mm^3 (thickness of 2 mm), it has a longitudinal form with a linear central groove and the two edges are on the same planar surface. The main processes applicable to the scrap can be milling, drilling and spray coating. From a physical point of view, ABS' operating temperature range is from -30 °C to 70 °C. It has no electrical or thermal conductive properties and it has good resistance to external agents except for strong acids or if long exposed to UV radiations. The material is a non renewable resource but it is recyclable (embodied energy related to recycling of 32 MJ/kg).

In Phase 3 (Designing with scraps) we propose some concept ideas based on ABS scrap reuse such as a shelf tool, a towel rack or a fruit holder. However, the mechanical and dimensional analysis points out some critical aspects of the scrap unit for its flexural and torsional properties. This aspect and a negative answer to the three preliminary questions blocked the development of the concept proposals. For this productive scenario we cannot find a valid reuse application for the ABS unavoidable scrap, so according to the waste

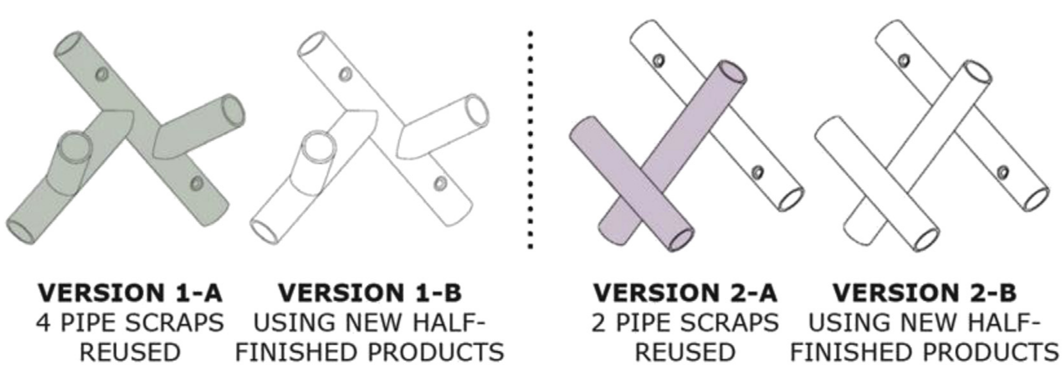


Fig. 7. The two versions of the hanger's metal body.

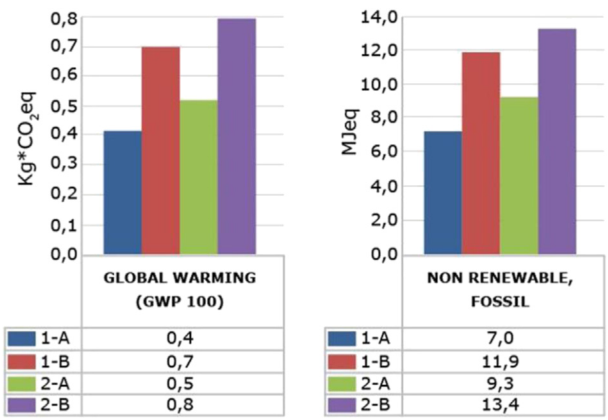


Fig. 9. Results emerged from an LCA of the two versions (the 4 solutions 1A, 1B, 2A, 2B) of the hanger's metal body (GWP and Non renewable fossil resources extracted).

management operations proposed on the method, the second hierarchical strategy to take into consideration is recycling, which actually is the practice adopted by the company [Fig. 10].

The two case studies reveal how different the results could be and how they are influenced by the single productive scenario, the materials and the scraps' characteristics involved in defining a potential reuse application.

4.3. Application of the method to already existing products

In order to demonstrate how the method is applicable to several industrial contexts and technologies, we present six existing products based on scraps reuse showing how through the application of the method it would have been possible to obtain the same design results but in a more structured way. We did not conduct the economical and environmental assessments in Phase 3 because the aim of presenting them is just to provide ideas and inputs to the designers and not to define if they are advantageous or not. Case studies are related to products based on scrap reuse of six different kinds of material. The products analyzed in the six case studies are presented in Fig. 11.

The first case study (Fig. 11A) consists in a screen designed by the American company SkateStudyHouse which reuses multilayer wood scraps derived from panel's milling for skateboards. The potential application of the method for this design starts with the optimization of the geometrical shape distribution on the multilayer wood panel for Phase 1 in order to reduce scrap production.

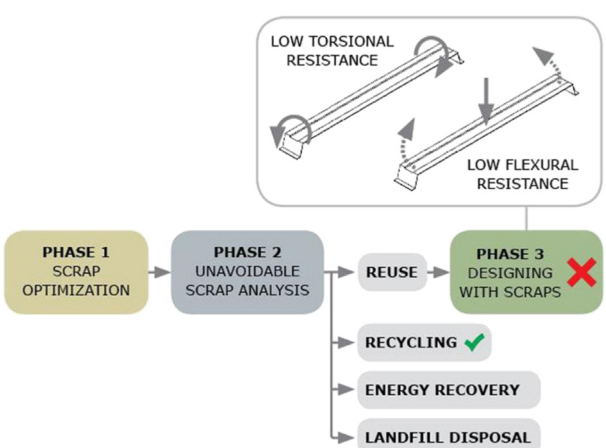


Fig. 10. Phase 2 pointed out some critical aspects of the scrap which didn't allow to define a valid concept idea.

The unavoidable scrap analyzed in Phase 2 point out a single rigid panel with internal holes (corresponding to the milled skateboard shapes) which form a pattern. This pattern assumes a decorative function in Phase 3, where the geometrical, dimensional and aesthetical properties of three multilayer wood scraps are reused by connecting them through six hinges that allow the panels to stand vertically, obtaining a decorative wood screen for interiors (PM1 Low intervention grade, PM2 Hybrid product, connection needed).

The second case study (Fig. 11B) consist in the reuse by the Italian company Alisea of graphite swarfs derived from the cutting, milling and turning of compressed half-finished graphite blocks used for the production of electrodes for EDM (Electro Discharge Machining) by another external company. The electrodes involved in swarf production are cylindrical rods, so even after optimizing the use of the graphite parallelepiped blocks intervening on geometrical parameters (Phase 1), it is impossible to avoid graphite swarf production which comes out from machining in form of fine powder. Phase 2 points out that every year 50–80% of incoming graphite blocks machined by the electrodes company become swarf and rejects. Approximately 10 tons/year of fine powder graphite swarf are produced by the company, which pays about 8500 €/y for its collection and landfill disposal by a third company. The graphite swarf is a black fine powder fragile if aggregated in certain condi-tions and with interesting electrical and thermal conductive properties for other possible reuse scenarios beside the solution adopted by Alisea, which consisted (Phase 3) in the development of an innovative material (patented) obtained by combining up to 80%of graphite swarf with a 20% of a thermoplastic technopolymer. Alisea designed an injection mouldable pencil which can be pro-duced by using this new composite material based on graphite swarf powder, entirely reusing the 10 tons of waste, avoiding costs for its disposal (PM1 No swarf modifications, PM2 Hybrid product, no connection needed).

The third case (Fig. 11C) consists in a reuse project by the Italian designer Paolo Ulian based on scraps derived from the CNC milling of standard marble slabs used for bathroom applications. Phase 1 consists in this case in adapting the dimensions of the components to the those of the half-finished slab and in a general component simplification in order to reduce scrap production. The oval hole in the centre of the slab (the washbasin area) obtained by CNC milling generates the scrap component reused by the designer. Phase 2 pointed out how the marble scrap has small dimensions (46 × 30 cm) and mass (5.7 Kg). The marble slabs are polished before the milling phase, so the scrap already presents a polished aesthetical surface with no intervention needed. The reuse idea (Phase 3) of the designer consists in giving the marble component the function of a kitchen cutting board (PM1 No swarf modifica-tions, PM2 Hybrid product, no connection needed).

The fourth case study (Fig. 11D) is related to a furniture product designed by dutch designer Christian Kocx based on reusing scraps derived from injection moulding process. Phase 1 consists in modifying those parameters involved in scrap production in order to reduce the mass of the injection channels, without compromising feasibility and manufacturability aspects. The unavoidable scrap (Phase 2) derived from injection moulding evidences how the scrap is comparable to a small rod made of a defined thermoplastic polymer able to modify his geometrical and dimensional properties if heated. The designer used this aspect to realize a chair (Phase 3) made of hundreds of polymer scraps placed in a heated mould: when the scraps are close to the softening temperature, they connect together in many point obtaining a single structure (PM1 Medium intervention grade, PM2 Only scrap product, connection needed) where the scraps involved have been geometrically modified but still recognizable in the final product.

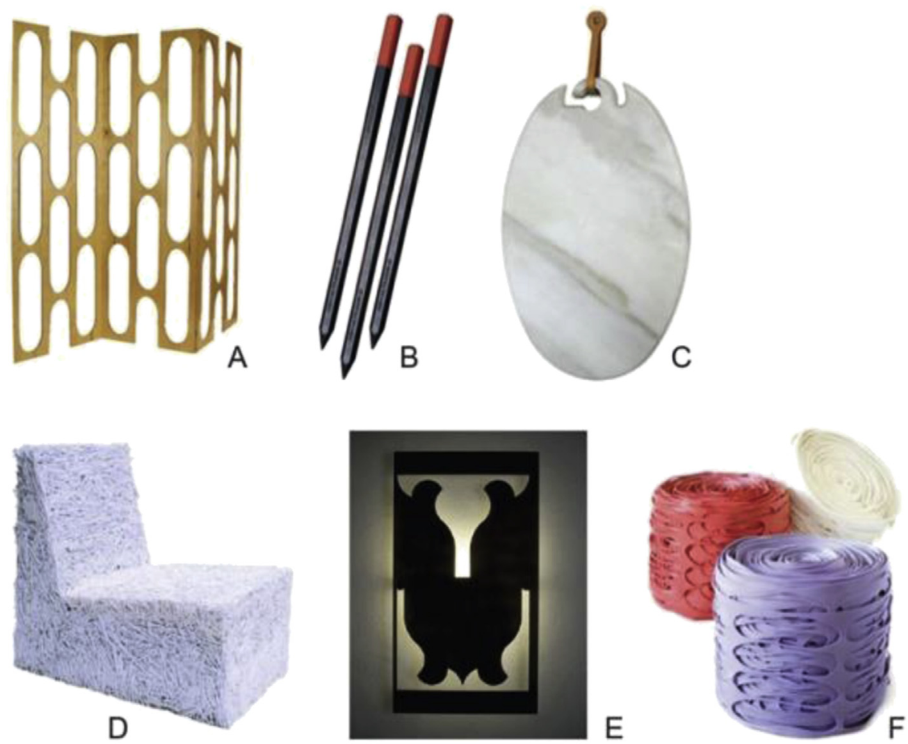


Fig. 11. The six case studies of existing products based on scrap reuse.

The fifth case (Fig. 11E) we present is about a reuse project by Italian studio Broggidesign based on scraps coming from the laser cutting of steel sheets used for obtaining components for a table for interiors. Phase 1 points out how in this case no operations of optimization were conducted with the aim of reducing scrap production. By simply accosting the two components to cut it, it would be possible to reduce scrap production. However, the avoidable and optimizable scrap's dimensions (Phase 2) are 750 × 400 × 3 mm for a weight of 5.3 Kg, presenting two cut areas. The metal scrap was reused (Phase 3) as the main component of a decorative lamp (PM1 Medium intervention grade, PM2 Hybrid product, connection needed).

The sixth and final case (Fig. 11F) presented consists in the reuse by the Italian design group Ricrea of elastomeric scraps derived from the diecutting of latex rolls used in shoe soles production. Phase 1 consists in intervening on the geometrical parameters, optimizing the positioning of the shoe soles shape on the diecut, according to the standard dimensions of the latex roll. The unavoidable scrap produced (Phase 2) is a flexible latex roll with repeated holes corresponding to the shape of the shoe soles. Ricrea group uses the dimensions of the latex scrap roll (especially a width of approximately 500 mm) to realize a stool (Phase 3) by rolling the scrap circularly from the centre to reach a diameter of about 450 mm for the seat (PM1 No swarf modifications, PM2 Hybrid product, no connection needed).

5. Results and discussion

Our research aimed to define a procedural design method focused on the reuse of industrial scraps, which represents a tool for design in order to minimize and reuse industrial scraps. As previously described, the lack of a clear method for designers is evident and entails to a deeper focus on solving a situation more than set it up from the front end of the design phase.

We applied the method to a first original case study (a steelwork company), designing two versions of a hanger reusing steel scraps derived from a cutting process. Each version has been compared to the same design realized starting from new half finished products. The first version of the hanger based on scrap reuse is economically disadvantageous (4.81 €/pz vs 5.37 €/pz) and environmentally advantageous (0.4 Kg*CO_2eq versus 0.7 Kg*CO_2eq for GWP and 7 MJeq versus 11,9 MJeq for Non renewable fossil resources extracted). For the second version of the hanger the scenario is inverted, since the metal scraps' reuse design is economically advantageous (3.29 €/p versus 3.74 €/p) and more environmentally sustainable compared to the one realized starting from new half-finished products (0.5 Kg*CO_2eq versus 0.8 Kg*CO_2eq for GWP and 9,3 MJeq versus 13,4 MJeq for Non renewable fossil resources extracted). Nevertheless, version 2A of the hanger is more impacting than version 1A (0.4 Kg*CO_2eq versus 0.8 Kg*CO_2eq for GWP and 7 MJeq versus 9,3 MJeq for Non renewable fossil resources extracted) because in 2A less waste material is reused, influencing the two life cycle assessments of the two versions of the hanger.

The second case study (polymer thermoforming) represents a scenario where the application of the procedural steps of the methodology conducts to define the scrap reuse solution as a not valid operating option. According to the procedural steps of the method, we identify recycling as the best scrap treatment operation, which corresponds to the practice adopted by the producer.

We present also six case studies of existing products based on industrial scrap reuse related to different materials and technologies. Through an inverted application of our scrap reuse methodology, we demonstrate how this design tool can be applied to several materials and manufacturing processes and how the same design results could have been achieved in a more precise and structured way by applying the tool we developed.

The method is at its first development phase and some limitations are evident. For example even if simple tools are used to assess different design solutions some of those tools do not belong to the culture of product designers, for this reason a further simplification could be useful. Furthermore additional tests of the method in different production contexts can entail a deeper understanding of possible scenarios.

6. Conclusions

To conclude, the qualitative skill of our proposed methodology enables to evaluate the potentialities of different materials and technologies in order to obtain and design products based on scrap reuse. In our opinion these results can be useful specifically to those designers that want to potentially start a professional activity based on products obtained by industrial scraps reuse, focusing their design strategies and choices on both economical and environmental considerations.

In last decades many design tools and strategies have been developed to optimize, reduce and reuse industrial waste production. The work we present focuses on industrial scraps reuse from a design driven point of view, pointing out how the industrial field presents a rigid and sectorial approach to the issue, while industrial designers face it in a creative way but often not related to industrial production logics and usually without environmental and economic considerations. This research outlined a method that could become a tool for industrial designers in order to evaluate the potentialities of developing product design concepts based on industrial scraps reuse, helping in establishing —starting from the front end design phase-if a reuse design operation is economically and environmentally valuable.

Appendix A. Supplementary data

Supplementary data related to this article can be found on line.

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