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Society and materials: an interpretation of the subject in the light of sociology and gender

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Abstract. The paper discusses the relevance of the link between gender and materials, in the framework of a more general reflection on the science-society relationship. In order to do this, the theoretical path is presented that the author and his colleagues followed, with the aim of using some concepts and theoretical and methodological approaches taken from social sciences for a better consideration of society and materials issues. The gender/materials connection does not appear to have been dealt with yet in a systematic way, although there are some interesting studies and insights. This connection instead appears very important in the light of a sociological reflection focusing on the relations among the social actors involved in the cycle of materials. The centrality of social actors within the processes that define the value chain and life cycle of products and materials is presented and, in this framework, the importance of design is stressed, together with other typical phenomena highlighted within social sciences such as closure or negotiation, power relations, etc. Particularly, considerations on gender appear important because they imply the possibility to include the different points of view, approaches and solutions of gender-diverse actors. Gender differences and gender related dynamics emerges as relevant in the definition of research priorities, in the analysis of needs, uses, and social and environmental impacts of materials and products is likely to limit the potential and distort the perspective of materials science. In this framework, existing data are presented that show that materials represent an area of scientific research (both academic and non-academic) where the under-representation of women is presently recorded and probably impacts on the materials sector as a whole. The proposed reflection on the relation between gender and materials is still a very initial one, but further research is advisable in light of the centrality of sustainable policy issues such as the Circular Economy (CE) where it is important to focus the attention on the role of social actors in the entire product cycle and not only in its final part (e.g., the purchase of consumer goods, their use, disposal, re-use, etc.). A further reflection on gender and materials could also be relevant for LCA.

Keywords: gender / materials / materials and society / circular economy / social sciences / sociology / life cycle thinking / LCA

1 Introduction – A broad reflection on Society and Materials

The reflection over Society, Materials and Gender that is being proposed here can be traced back to when a group of social scientists, to which the author of this article belongs, began to participate in the SAM Conferences. This group had been working so far on the issues of scientific and technological development according to an approach that is not a specialist but a generalist one, also characterized by some strong elements of interdisciplinarity. They first took part in one of the meeting in 2012 in Leuven. In the following editions, other contributions were given through papers and articles.

Overall, this effort, especially at the beginning, has been focused towards providing a point of view from the social sciences – and from sociology in particular – on materials. The pathway followed was somehow tortuous, the reason being that not much work has been done so far by sociologists and social scientists in general on materials as such. Of course, as it will be clear soon, there were many contributions – that have been used as much as possible – but there was not a systematic approach to the matter. On the basis of the existing contributions, some ideas were proposed that could be useful for continuing a reflection over society and materials that should be considered as just at its beginning. In the framework of this effort, it was decided to propose, in the SAM-11 conference, also a contribution on a very important aspect of the society and materials issue, connected to gender. Before presenting these ideas on the matter, it is important to propose the main steps followed so far by this group of researchers for approaching the society and material issue.

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The first step was in Aachen in 2013, at the SAM-7 conference. Some general ideas were presented in order to make it possible to deal with materials according to a sociological perspective. The social nature of science, technology and materials was stressed and, in this framework, it was held that materials are a topical issue for understanding the change of contemporary society and not a specialized field of enquiry. The absence of a "sociology of materials" was not, therefore, such a bad thing. Being in a broad field of enquiry made it possible to outline a connection between the concept of social subjectivity, on the one hand, and technology and materials, on the other. With the term social subjectivity, it was meant the capacity of people to think and act – individually and collectively – in relative autonomy from the prevalent social structures and to activate and develop new social relations. It was also noted that materials are part of a momentous societal process characterized by the amplification and diversification of social subjectivity with an increased mobilization of human energy. The issue, it was said, is to understand and manage the resulting phenomena [1].

The second step was represented by a keynote speech given in Liège in 2014, at the SAM-8 conference[1]. On that occasion, was presented the theoretical path that, within social sciences, has made it possible for them to deal with technology and materials. First, the focus was on the long intellectual and theoretical effort needed to make materials become also a sociological subject. On this basis, some analytical concepts were introduced (particularly the concept of closure produced Science and Technology Studies (STS) scholars and the related idea proposed on that occasion of a social cycle of materials) for dealing with materials in sociological terms. Were also presented the possible advantages of using such concepts for approaching and enlarging some analytical tools such as Life Cycle Assessment (LCA), based on the concept of Value Chain [2].

The third step consisted in focusing the attention on how all these issues were relevant for science and research policies. For this reason, the paper presented at the SAM9 conference in Luxembourg 2015 was on the so-called RRI – Responsible Research and Innovation – that at that time had already begun to inform the European Commission (EC) policies. In that period, some members of this group of researchers were working – among other things – at the MATCH project aimed at promoting policies for research and innovation on Materials (particularly, the construction of the MATerials Common House, the acronym of the project). It was stressed that the SAM conferences interest for materials and society was in line with the EC policy on Science and Society (and related programme, such as SwafS). SAM focus and EC policies appeared convergent because they both shared a strong awareness of the connection between society, on the one hand, and research and technology, on the other. Furthermore, it was also highlighted a convergence on the recognition of the importance of anticipating uses and outcomes of technologies for the success of research and innovation – one of the tenets of RRI [3]. In SAM9 a paper of A. Declich with J-P Birat[2] stressed the importance of expectations and narratives for studying the ways in which materials become a societal object (and a sociological subject).

The fourth step of this reflection took place in Rome, at the SAM10 conference in 2016, when it was proposed an enlargement of this analysis by discussing two cases in which the social dynamics of materials were evident, one concerning industrial symbiosis and the other urban regeneration (see [4]). Particularly, it was held that change and innovation concerning materials become possible in the context of a significant mobilization of social actors (and not only thanks to some targeted intervention). To this end, a hypothesis was formulated concerning a strong connection between materials innovation and use and social transitions (in that case, energy transition towards a post carbon society).

2 The centrality of Social actors in the materials cycle, time, innovation and transition

One of the merits of the approach presented so far is that it makes it possible to explore the possible connections between materials and some epochal social process. Gender transition is one of the most important of our time, concerning – in very general terms – the ever-greater improvement of women status and role in society – in the working and family life, in politics, research and so on. Is this process relevant for materials sector and, in case, in which way?

In order to do this, it is necessary to go back to the second step of the pathway described above, when it was proposed the concept of "social cycle of materials". It is partly independent from the concepts used within the Life Cycle Thinking (LCT) and is related to the concept of closure proposed by Bijker et al. [5, p. 12], defined as "when a consensus emerges that a problem arising during the development of technology has been solved". It is to stress that, according to the two authors, closures are recurrent: "closure and stabilization (...) are not isolated events; they occur repeatedly during technological development" [5, pp. 12–13].

The idea that the social cycle of materials depends on the (social) stabilization of certain materials as well as on the following possible adaptations and further stabilization also implies the idea of passing of time.

The concept of "social cycle of materials", it should be also added, is different from others used within LCT because it does not abstract from the fact that the material (s) we are using today is (are) being continuously innovated. Giving importance to innovation means that materials are to be considered as inherently characterized by diachronic aspects: in a certain productive chain,

[1] The keynote was the basis for the article published by d'Andrea and Declich [2].

[2] "Narratives and materials", Jean-Pierre Birat, ESTEP, Andrea Declich, Laboratory of Citizenship Sciences, presentation at the SAM9 Conference in Luxembourg, 12 May 2015.

activities such as acquisition of raw materials, processing, marketing, use and disposal take place according to ever changing approaches and technical solutions. Oftentimes, LCT approaches assume that all these segments of production activities are being carried out according to a certain technological framework (we could say "synchronically"). If this abstraction is very useful in light of measurement and evaluation purposes, it ends with concealing the social aspects of materials rooted in the actors' mutual relations implied by the adoption of the different technical solutions. As a matter of fact, this is one of the aspects for which a new approach to Life Cycle Assessment (LCA) is being developed, the so-called consequential LCA. Nevertheless, hypothesis over change are needed, as suggested, among others, by Rugani et al. [6]. This is also in line with what Birat suggests on this regard, particularly when he says that one of the shortcomings of most LCT related analysis is this abstraction from the time dimension [7].

What is worth stressing is that there is a social fabric that is relevant for describing and explaining "materials in action" (paraphrasing the famous sentence of Latour) that is inherent to the innovation process. In particular, we have to consider all the relevant elements of change that are social in nature and, anyhow, have a social origin such as visions, ideas, expectations, projects, conflicts, investments, decisions, scientific research, dialogue between diverse actors, etc.

The peculiar aspects of innovation make the relations among the relevant actors not completely overlapping with those implied by the use of the value chain concept [2]. Nevertheless, the concept of value chain is particularly important for an analysis of materials, including of their societal aspects, because materials take a social and economic importance depending on the ways in which they enter the exchanges among actors all along the productive processes that lead to the final product[3]. We can say that considering all these social aspects of materials becomes even more relevant when considered within value chains composed by several different actors. Innovation – especially if analyzed in the context of a value chain – implies the activation of these actors, particularly their decision to act and, possibly, change the current productive and economic arrangements. In brief, we could say, not too much metaphorically, that all this implies some social energy.

These elements are typical of transition processes. It was held, at the SAM10 conference, that it is difficult to explain innovation – including in the materials field – without considering wider societal processes that constitute the context of innovation [4]. Particularly, it was affirmed that one of the processes in which innovation in the materials field could be interpreted is the transition toward the circular economy.

[3] The relevance of the Value Chain approach was particularly stressed in the framework of the MATCH project. It is to be noted that part of the study of this matter was made possible by our participation in it.

The social cyclicity of materials implies the centrality of social actors, of their roles and actions and, in this context, it helps to better understand and, anyhow, to shed some new lights on complex processes such as social transitions. For this reason, this concept is particularly suitable for considering gender dynamics within the materials sector.

3 Gender, technology and design: ideas for approaching the gender and materials connection

We can start by acknowledging that the actors' role(s) is (are) marked by the actors' gender (for individual actors) or by gender dynamics (for collective actors). In the following, some reflections are proposed for considering the consequences of this acknowledgement.

These issues will be dealt with by making reference to some women scholars who studied gender and technology relations, particularly Judy Wajcman. It is important to stress that the issue of gender and materials did not emerge as such in the social studies of technology (STS) and that the topic of gender was not much considered, in this field of study at least up to the last 15 years. Wajcman says [8, p. 149], in this regard, that:

> "(...) the ways in which technological objects may shape and be shaped by the operation of gender interests or identities has not been a central focus"

Nevertheless, Wajcman and colleagues have done a critical work on gender and technology that is of great help for us, provided that all the concepts, ideas and findings are adapted to the issue of materials.

As stressed above, materials are to be understood as technologies (even if very particular ones) and, as for other technical objects, the problem is "shaping" them or, better, construct them also in terms of their social meaning. For this reason, the issue of design is of the utmost importance for this reflection.

Design is a broad concept, encompassing what is meant as design of a product – industrial design – as well as design of a specific material.

The two things meant with the word "design" often go together. An example could be the self-cleaning surfaces in some monuments in Rome [9,10] that have been crucial for the entire final aesthetic aspects of the buildings these materials have been thought for. Sometimes, some final products have been imagined because of the existence of certain materials. For this reason, the word "design" will be used according to both meanings.

The concept of design is important here because it is at the core of the very definition of material [4] and attributing properties to matter is at the center of the science of materials. Thinking at the design phase help us think of society and materials relations not only in terms of the impacts materials have on society (through consumers habits), but also in terms of the ways in which materials are produced. This approach could help also in anticipating some of the social and economic effects of the use and diffusion of materials and related innovations.

A Norwegian woman researcher in ICT, Bratteteig [11], has worked on the concept of design under a gender perspective. She stresses that design is "the road from an idea to a finished artifact" and is based on "vision making", "seen as levels of abstractions and detail worked on in parallel during the design processes". According to her, vision making has the following interesting characteristics:
– "the vision may need re-vision after some sketching work, the specification may need some extra sketching;
– the vision that guides the design is created by the individual designers involved in the process, on the basis of their knowledge and skills in design and of their professional and cultural values and ideas;
– visions are created when ideas and materials are set to meet;
– visioning is a situated activity to a large extent determined by what the designers know about design materials and future use situations;
– sketching aims to make visions more concrete; sketches are used as tools for thinking as well as for communication."

The creative aspect of design connected to the idea of "vision making" would not be that surprising if they would not imply several moments that are social in nature, based on close relations among the actors involved in the process. Bratteteig [11] underlines that:
– "design processes are decision processes;
– decisions in design concern the resources for the design process and the design result;
– visions of system usage – the new way of doing things, the change – are constructed in negotiations between people with various roles, responsibilities, and power, between people from different organizations, i.e., design and use organizations;
– existing power structures are normally strengthened in a new system;
– design is a work process that can be analyzed in the same way as other social processes."

It emerges that, at the center of this process, there is a social fabric in which actors' gender clearly plays a role because of the collective nature of design and, therefore, of the inherent power relations. Bratteteig stresses that "design is an individual process but carried out in the context of a group in an organization – it is a social process as well". Therefore, design processes are influenced both by the individual designers and by the design group and by group process as well as by external factors such as external agendas, goals, time limits, available people, resources, and power games beyond the control of the group.

No wonder, therefore, that Bratteteig puts at the center of her analysis the observations that "Designers do have a gender" suggesting that this perspective has to be fully considered. Particularly, she defines the issue by stating that a feminist perspective on the design context aims to identify actors and their interests, their resources and strategies for exercising power with a particular focus on gender. For this reason, she considers relevant the presence of women in the scientific sectors she belongs to, ICT. Although it is a sector that is somehow far from the materials' one, it is characterized as well by a lack of women – as we will see with more details below. In this framework, she considers relevant to ask if women design differently or if female decision makers decide differently. Both issues seem relevant to her and, one might add, for the materials sector.

These issues, of course, should not conceal the fact that – according to Bratteteig – the lack of women in the ICT sector, the injustice of not including them, is the basis for an argument for changing the current state of affairs based on fairness and principles of equal rights. "Whether or not women behave differently – and for whatever reasons – is perhaps less interesting than the fact that many women are not included in these processes", have different opportunities for access to technological resources in society and are victim of injustice.

These considerations on gender and design, even if related just to ICT, have a general relevance. But for finding the possible ways to connect them to materials – including the diversity of thinking and behavior women are bearers of – it is necessary to resort to some insights from gender and technology studies, which has made the point that visions, negotiations, and ideas about users' experiences with the product constitute the focus of the design process.

When thinking in terms of visions of the use, the issue of the user/design relations is being raised. An important reflection on the matter was carried out by Wajcman [12], concerning the so-called "deconstruction of designer/user divide", according to which users appropriate technologies. Wajcman [12, p. 455] says, in relation with studies about particular (domestic) technologies, that

> "gendering does not begin and end with design and manufacturing: domestic technologies are also encoded with gendered meanings during their marketing, retailing and appropriation by users. (...) marketing and consumption are all part of the social shaping of technology".

Ten years later she confirmed this statement in more general terms [8, p. 149].

> "Such a mutual shaping approach recognizes that the gendering of technology affects the entire life trajectory of an artefact. Indeed, feminist research has been at the forefront of more general moves within Science and Technology Studies (STS) to deconstruct the designer/user divide, and that between production and consumption, emphasizing the connectedness of all phases of technological development."

Therefore, dialogue and negotiations, in different forms and beyond the ideas and visions of designers, impact on technologies. The idea of the existence of strong interactions (and not simply mutual understanding) between users and designers, consumers and producers changes the ways in which the entire production process and cycle is figured out. Examples of technologies that changed a lot on the basis of the ways in which women users actually appropriated them are various: telephone [11] and bicycle [14] are but two of them.

Unfortunately, as said before, according to Wajcman [8, p. 149] these processes have been identified and outlined, but it seems that there is not a deep and wide knowledge of them:

> Whilst innovations are seen as sociotechnical networks, it has been largely incumbent on feminists to demonstrate that gender relations inform these networks.

From what has been said so far, it can be affirmed that, through the use of the category of design emerges a general relation between the social nature of materials and gender. As observed above, this connection does not exhaust the entire complexity of the social character of materials, as what happens downstream is also very relevant, as demonstrated by the consumer-producer relation. Nevertheless, as far as gender is concerned, there is not a well-developed field of studies on all this: while there are many useful concepts and case studies, there are not many large scale and systematic studies. Furthermore, the concept of design that was introduced above is general and is related mostly to the design of objects and not explicitly of materials. It can be asked if the focus on design of objects is relevant for materials and, particularly, to what extent it is relevant to our theme of "Gender and materials".

A British social anthropologist [15,16] says that modern thinking connected to material life (including some reflections on materiality) tends to make materials invisible. Kuchler [17], an anthropologist as well, uses the term of opacity. Caiati and Declich [4] stressed the issues as connected to the process of signification of materials. The issue is raised by Miodownik [9, p. xiii-xiv], a materials scientist and a science writer, who says that:

> The materials themselves are often surprisingly obscure, despite being all around us. On first inspection, they rarely reveal their distinguishing features and often blend into the background of our lives. Most metals are shiny and gray; how many people can spot the difference between aluminum and steel? Woods are clearly different from each other, but how many people can say why? Plastics are confusing; who knows the difference between polyethylene and polypropylene?

In a certain sense, the result is that objects conceal the process of their formation, which includes materials. This can be an explanation of the tendency to talk of social aspects of materials mainly in terms of consequences of the use of certain materials contained in certain products, once they become objects of consumption. In general, it can be said that if materials disappear behind (or inside/within) objects, the same is probably true with the connected social and gender dynamics.

This is not just a theoretical statement. As observed in general terms in relation to the design process, a certain material is the results of negotiation between social actors. It could be added that in the social cycle of a material enter different subjectivities. In this regard, Barry [18], a geographer who studied some big pipeline works, states

> "metallurgists [...] are mediators between forms of economic calculation, government regulation and the analysis of material properties and structures"

The approach presented here, focused as it is on the analysis of the "social fabric" underlying the production process, should prove even more useful for materials than it has been for objects, because of some special features of materials.

In particular, some concepts – initially used for analyzing certain production sectors – are of a particular interest, i.e., the position of the materials within the value chain and the fact that materials are considered as enabling technologies.

The concept of value chain is used often by those who work in the materials field[4]. Each ring of the chain implies a relation of an economic and social nature between different actors (producers and users of certain goods or services being exchanged) that entails power (market, technological and/or gender power, etc.). Materials tend to enter upstream in the value chain (hence their "invisibility"). This implies that such relations are more difficult to single out but, even if less visible, are even larger in number. In a certain sense, we could talk of the "intensity" of the social factor that appears if we consider the social implications of the value chain of a specific material (this is something that is very important when analysis of the social and economic role of materials such as steel are considered, as underlined in some of Birat's works [19]).

New materials are considered as "enabling technologies" (for a definition see [20, p. 9]). Materials in general – and not only the new ones – are not necessarily specific to a certain product but are used for different economic activities. This does not mean that their specific characteristics do not matter as they are "diluted" in the flow of final goods production[5]. The ways in which materials are designed and the negotiations connected to materials production have impacts that could be thought of as very broad. We could talk of the wide "extension" of the social factor implied by the social relations of the value chains of different materials.

Putting together what have been called "intensive" and "extensive" social factors, we have an image of the materials sector as a complex social process. It could be said that the metaphor of chain[6] – even if it helped to carry out this analysis because of the focus on the exchanges between actors – could be substituted with the metaphor of network, that would represent this complexity better than the imagine of a line. Networks are characterized by loop-

[4] The concept of value chain was at the basis, for example, of the activities of the EU funded MATCH project. Some of the reflections that are being proposed here have been made possible by the work done in that context by the author and his colleagues.
[5] There is an analogy with oil, a raw material, and national economic performances; apart from the case of gasoline, it is difficult to mechanically connect the political dynamics of oil production to what happen in our economic systems even if the existence of the oil's impacts on the economy is evident.
[6] The term value chain is *filière* in French and *Filiera* in Italian, coming from thread, "filo".

effects, feedbacks and retroactions. Rafols et al. [21], who studied nanomaterials, underlined that in each passage from material to final product, there could be an innovative intervention (i.e., a decision, a negotiation). They proposed the idea of distributed innovation of nanomaterials and, on the basis of what we said, this idea could be transferred to materials in general.

Furthermore, we want to stress that materials by themselves enter the design process of the finished product since they bring about experience connected to products. Karana et al. [22] talk of "Materials experience" and of the fact that the senso-aesthetic characteristics of materials enter the very process of product design. On the basis of these observations, Declich and Caiati [4] stressed there is not only a signification process of object, but also of materials. Wilkes pints out that this process has a social nature and not only a psycho-physical one and it is "labor intensive" [23].

In general, it seems that notwithstanding these important observations from some scholars, there is not a widespread awareness of materials and of the related dynamics. What should be stressed as a consequence of what has been said above is that materials are affected by dynamics that are not only technical in nature. Materials are a class of technology and for them holds what is true, according to Wajcman [8, p. 149], for technologies in general:

> the notion that technology is simply the product of rational technical imperatives has been dislodged. Objects and artefacts are no longer seen as separate from society, but as part of the social fabric that holds society together; they are never merely technical or social.

What can be said on the basis of all these contributions is that gender dimension is deeply relevant when the social nature of materials is considered and that, consequently, it is an inescapable issue for consistently approaching the general issue of society and materials.

4 Gender in the materials field: a slightly out of focus picture of the situation

In the literature, there are not many examples of studies on materials that prove the importance of social dynamics and, more so, of gender dynamics. A discourse on gender and materials, to the knowledge of the author, is a field almost not explored, at least systematically.

Nevertheless, all what was said about gender, technology and design can be applied to materials (see above what was said about negotiation, choices, definition of visions and ideas in the framework of design, distributed nature of innovation concerning (nano)materials, etc.) and we can think that all the elements are available to think that social and gender dynamics are important for materials. This undervaluation is not surprising, since scholars say that the relation between women and technologies has been for long time a relatively neglected issue. Anyhow, in order to first address the issue in more empirical terms, some entry points have to be singled out.

The issue of the presence of women in scientific and professional sectors connected to materials is a possible way to approach the issue of gender and materials. It is an important issue: the social nature of materials implies that social actors affect – through their actions that implies some form of presence – the social cycle of materials. Particularly, in order to have a first idea of women presence in the sector, in the following the attention will be focused on research and professional fields related to materials. Thanks to the data on Europe provided mainly by the last edition of the report "She Figures 2015" [24] (EC 2016), the following phenomena can be observed:

- exclusion of women in higher education for materials related sector (Horizontal exclusion);
- women are under-represented in the scientific research;
- the under-representation is stronger in research sectors connected to materials;
- there are signs of improvement of this situation;
- the under representation is stronger in industrial research compared to academic research.

Before proceeding, it is necessary to remind that these are second level data, that were collected and processed not to represent the situation of women within the materials field. Consequently, they are a little bit out of focus, since they do not represent directly the phenomena we are interested in and with the desirable precision. More in general, these data concern education attainment level or career of women in Europe in sectors that entail materials sciences or are connected to the materials field. Even if they do not cover entirely our area of interest, i.e., the presence of women within the materials field, they can be considered as indicators of such presence, even if not precisely, and consequently are anyhow relevant for the discussion being proposed. In particular, such data represent both the presence of women in research – those related to materials are advanced sectors in which research is relevant – and in higher education – that is a necessary and initial stage of a career within such and advanced economic field. Furthermore, it should be stressed that the data we are using are sometimes not homogeneous since they refer to different European countries where diverse survey methodologies are practiced.

Consequently, it is to underline that this is just a first attempt – on the basis of the theoretical considerations presented so far – to look at the materials field with the category of gender in mind. It is an effort aimed at opening a reflection more than at presenting an overall, and certainly not, "definitive" picture of the situation.

The critical connection between women and materials appears clearly by looking at the different access to the first levels of higher education that are most relevant for being enrolled within the materials field. "She Figures 2015" stated that "Men are more than two times as likely to choose engineering, manufacturing and construction, whereas women are twice as likely to pursue an education degree" [24, p. 20]. There is a lower enrollment of women compared to men in the fields of "Science, maths and computing plus Engineering, manufacturing and construc-

tion", were "women represent only 31% of students and 35% of graduates at the first level of tertiary education" [24, p. 128]. Furthermore, it is reported that in Europe, in the year 2012, women graduates, at the ISCED 6 level[7] (post graduate) in engineering, manufacturing and construction were 28% [24, tab. 2.2].

It can be observed that this initial bias – that represents a lower level of entry of women compared to men in research positions and in professions relevant to the materials field – is strengthened throughout the academic career. Women performances are good as students, also after graduation. Then their position compared to men begins to worsen. This is very clear from the figure 6.2 of "She Figures 2015" (Appendix A) in which it is shown that the percentage of women in the different positions within the academic career begin to worsen once they access working position (grade A, B and C) (see European Commission 2016, 128).

This bias concerning the careers of women is not typical of science and engineering sectors since – according to "She Figures 2015" [24, pp. 127–128] – it characterizes all the academic careers in Europe. The difference is that, for the Academic sector as a whole, women are the majority at the entry levels: "In 2013 (...) women in the EU represented 55% of students and 59% of graduates within the first level of academic education" and "the trend is reversed at the level of postgraduate tertiary education (ISCED 6), where women represented 46% of students and 47% of graduates in 2013" [24, p. 127]. It is worth stressing that in both cases there are signs of improvement between the situation of 2007, according to "She Figures 2015", while such signs are weaker (and not univocal) for the science and engineering sectors (European Commission 2016, 128). In general, women performance emerges as good and better than those of men, as long as they are student, which leads us to think that there are factors of exclusion of women that are independent from merit.

Another phenomenon that suggests a critical position of women within the materials field is the under-representation of women in research in general. According to "She Figures 2015", in 2012 women researchers were only 33.0% in Europe (EC 2016, 63, fig. 4.1.).

Considering Europe as a whole, women in Higher Education Sector research are 41.0% (EC 2016, 68, fig. 4.5), in Research within government structures they are 41.6% (EC 2016, 69, fig. 4.6) and in industrial research they are 19.7% (EC 2016, 70, fig 4.7). Although there are signs of improvement of the presence of women in all these three sub-sectors of research, between 2005 and 2012 and apart from the comparability of all these data, what emerges clearly and that is relevant for our discussion on women and materials, is the strong difference in the presence of women in industrial research, where it is particularly low. It is almost clear that it is in these sectors that some of the important social dynamics and interactions connected to the social nature of materials take place.

Furthermore, in Europe, the pool of women researchers tends to concentrate in some subsectors of research compared to others. "She Figures 2015" indicates that in 2011 (EC 2016, 67, fig. 4.4) 64% of women researchers carried out activities within higher education institutions and just 22% of women researchers were within business enterprise. The rest was distributed between the government sector research (12.5%) and the remaining proportion within the private non-profit sector (1.4%). Men are relatively less present in the Higher Education Sector (46.1%), and far more active within business enterprise research (44.2%). Their distribution in the other two sectors was less relevant compared to the women case (8.9% of men are within the government sector and 0.8% in the private non-profit sector). All research sectors are dominated by men and women researchers tend to be concentrated in those in which the obstacles seem to be lower.

Given this general picture, we can have a look at what happens within the research sectors most connected with materials. There are some difficulties connected to diversity of sources used by the "She Figures 2015" Report and, particularly, to the diversity of the criteria of collection and aggregation of relevant data. Anyhow, in order to have some reliable hints it is useful to look at women researchers within the "engineering and technology" sector. In this case too, because of the nature of available data, we cannot carry out too much in-depth analysis – for example, we do not have data for all the European countries. Anyhow, since we are looking at the trends and "orders of magnitude" of these phenomena, we can afford some imprecisions. Given all these caveats, it emerges that the presence of women in "Engineering and technology" research is generally the lowest in the three sectors of Higher Education Sector, Governmental and Business Enterprise Sector (EC 2016, tab. 4.2, 4.4 and 4.6).

According to the "She Figures 2015" Report, "there are signs of greater representation of women within 'non-traditional' fields such as engineering and technology" in the Higher Education Sector (EC 2016, 61). In the Government sector, this presence grew between 2005 and 2012 in 20 out of 28 countries (even if just 10% of the researchers work in this sector of the research labor market, EC 2016, 87). There seems to be no improvements in the engineering and technology field or the business enterprise research sector since "the proportion of women researchers decreased in ten out of 15 countries (BG, CZ, FR, HU, PL, RO, SI, SK, RS, TR)" (EC 2016, 92). The data concerning the industrial research sector are not very accurate, therefore this observation cannot be considered as valid for the whole of Europe. Anyhow, the fact that there are signs of decrease of women presence can probably be interpreted as an indicator of their general weakness in this portion of the labor market.

[7] The International Standard Classification of Education (ISCED) is the UN framework for classifying educational programmes at different levels. According to "She Figures 2015", "The International Standard Classification of Education (ISCED-97) categorises education programmes by level. ISCED-97 Level 6 (also referred to as ISCED 6) covers: 'The second stage, which leads to the award of an advanced research qualification (e.g., PhD, non-PhD programmes with an advanced research component). The programmes are devoted to advanced study and original research' " [24, p. 19].

Table 1. Total and STEM employment by gender and educational attainment, 2000 and 2009 (thousands of workers). Source: Beede et al. [25].

	Male		Female		Percent Female	
	2000	2009	2000	2009	2000	2009
All workers	69.098	73.580	60.619	67.058	47%	48%
College-educated	18.995	22.167	16.415	21.433	46%	49%
STEM workers	5.321	5.640	1.680	1.790	24%	24%
College-educated	3.259	3.738	1.002	1.199	24%	24%

Source: ESA calculations from Census 2000 and 2009 American Community Survey public-use microdata.
Note: Estimates are for employed persons age 16 and over.

Table 2. Employment in STEM occupations in 2009 (thousands of workers). Source: Beede et al. [25].

	Male		Female		Percent Female	
	2000	2009	2000	2009	2000	2009
STEM total	5.321	5.640	1.680	1.790	24%	24%
Computer science and math	2.202	2.534	940	929	30%	27%
Engineering	2.185	2.079	318	330	13%	14%
Physical and life sciences	551	553	310	374	36%	40%
STEM managers	382	474	111	157	23%	25%

Source: ESA calculations from Census 2000 and 2009 American Community Survey public-use microdata.
Note: Estimates are for employed persons age 16 and over.

The situation seems to be similar also in the US. In this case too, we do not have data explicitly concerning women in the materials field. We can use, anyhow, other indicators as proxies to this phenomenon, particularly data concerning relations between University education in the STEM sectors (Science, Technology, Engineering and Mathematics) and the presence of women in STEM-related economic sectors. Probably the category of STEM is too large for representing exclusively women within the materials field but, as it is for the European case, it provides a general picture of the situation.

In a 2011 publication, the U.S. Department of Commerce highlighted [25] the following phenomena. Women are disproportionately underrepresented, as in the STEM sectors they were, in 2009, only 24% of the workers while they were, in the same year, 48% of the whole workforce [25]; college-educated women were, in 2009, 24% of the workforce within the STEM sector without any improvement compared to the year 2000, while college educated women were 49% of all the workforce with an improvement compared to the year 2000. As for STEM types of jobs, the presence of women grew significantly in those positions connected to physical and life sciences, and only very slightly in engineering and management positions; the presence of women declined in Computer science and math jobs. What is important for getting some hints about the materials field is that jobs in engineering represented 14% in 2009 [25] (Tabs. 1 and 2). Barriers at entry in STEM occupation are also highlighted by the report of the US Department of Commerce since it is stated that "women hold a disproportionately low share of STEM undergraduate degrees, particularly in engineering" and that "women with a STEM degree are less likely than their male counterparts to work in a STEM occupation; they are more likely to work in education or healthcare" [25].

It can be said that there are good reasons for thinking that, in the materials field, there is a strong horizontal and vertical segregation of women even if it is difficult to provide an exact measurement of the situation.

Even if the data are still not refined enough, there are other, somehow more impressionist hints, about the situation of women in the materials field.

Miodownik [26], a materials scientist, in one of the few reflections on society and materials, provides a particular description concerning how that senso-aesthetic and physical properties of structures are designed and used by different professions and at different scales (reported in the Fig. 1).

Beyond the general relevance of this description for the issue of society and materials, what is interesting of this figure is that most of the professions listed as involved in the design and using senso-aesthetic and physical properties of different structures are not dominated by women. While this cannot be a certainty in professions such as designers, artisans and jewelers, we have just seen that the available data – as imprecise as they are – indicates that it is probably the case for materials scientists, engineers and, probably, architects.

Wajcman [12] clearly pointed out the importance of "absence", especially because it is the result of an almost evident active exclusion (as in the case of University or

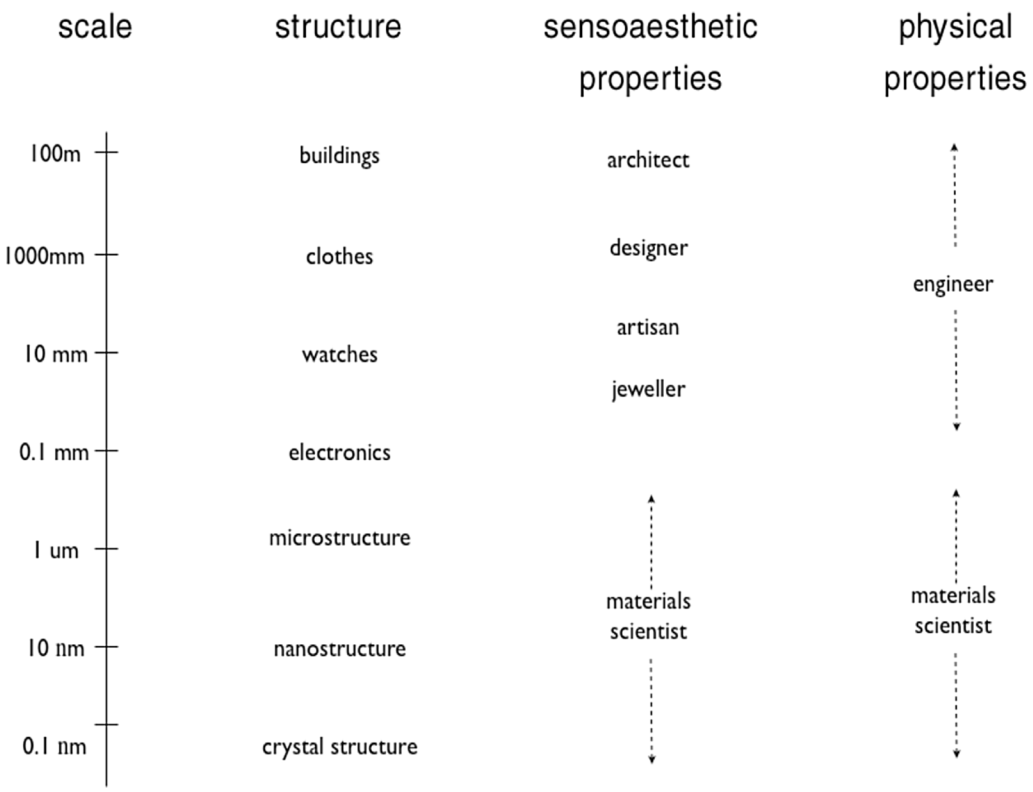


Fig. 1. A scheme of how the senso-aesthetic and physical properties of structures are designed and used by different professions and at different scales. Source: Miodownik [26].

careers in the STEM sector). Therefore, when thinking at the social actors active in the materials cycle, we should focus on the complementary concepts of presence and absence. The risk is that, in absence of a voice, of conflicts or of negotiations, we might think that a certain social actor is not there intentionally or on the basis of a consensus and therefore as the result of a marginalization process.

Wajcman [8, p. 149] states that research has clearly demonstrated that marginalization of women from the technological community has a profound influence on the design, technical content and use of artefacts.

There are good reasons – on the basis of the data presented, even if not tailored to our analysis – for assuming that this holds also for materials. The importance of this phenomenon is evident since some recent research results indicate clearly that there is a positive relation between diversity in gender and the likelihood of introducing an innovation [27].

Miodownik [28] talks explicitly of the importance of increased presence of women in the materials fields as an important achievement: "one of the biggest problems of engineering and of its social image is the gender balance. Gender equality will change what engineering is and how it is done. It will change which problems are chosen and how they are solved."

These considerations are relevant also for the issues that have been at the center of the debate on the relation between society and materials in SAM Conferences.

These conferences have always dealt with two themes, LCA theories and methodologies and the Circular Economy. Gender issues might enter both themes, probably introducing some innovation compared to the previous situation. Gender issues are indeed dealt with in LCA, particularly in Social LCA, but attention is paid mainly to impacts on women of certain productive or technological initiatives to be evaluated. On the basis of what has been said so far, it might be possible, and advisable, to consider the role of women also as a social actor within the technology social life cycle, including of materials.

As for the Circular Economy, it can be said that it is the context in which materials are mostly dealt with today. Economic activity "has to be" circular and materials should abide by this imperative. Murray et al. [29], quoting a UNEP Report, stress that the Circular Economy implies a continuous effort of design and re-design. Materials obey the same requirement of a continuous design, and we have seen how much gender issues are relevant for properly dealing with this issue. According to the European Environment Agency Report [30, pp. 17–18], another enabling factors, beyond design, for the success of the Circular Economy is the activation of "Circular business models". The entrepreneurial process, therefore, appears as crucial, and, within this process, so do the mobilization of actors and the organization of innovation. How to foster gender as a relevant variable within the innovative and entrepreneurial processes is something that should be further analyzed also in the light of the strong connection between Gender diversity and innovation.

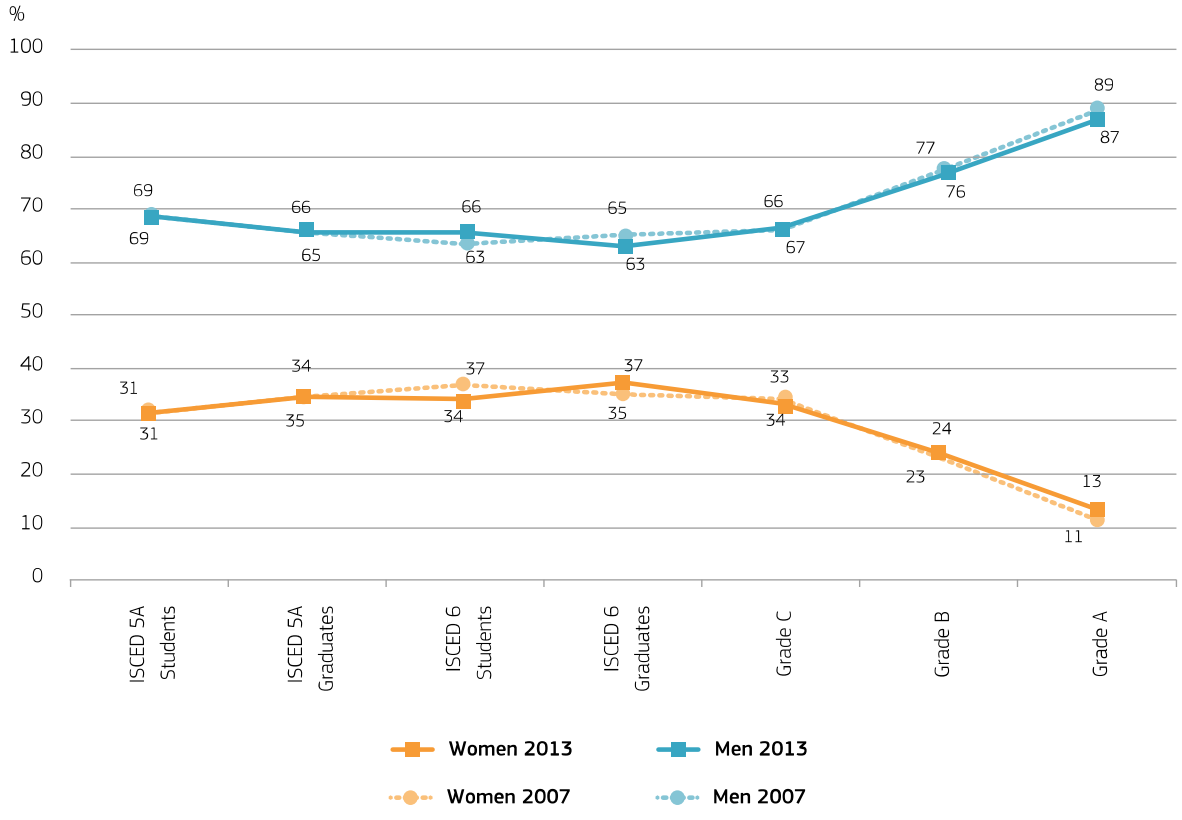
5 Concluding remarks

This article has posited that the reflection carried out so far on society and materials issues is also relevant – with some critical adjustment – to analyze the connection between materials and one of the most important societal issue of our times, i.e., gender.

A theoretical path was provided on the basis of some preceding work on society and materials and on the basis of the work of women researchers on gender and technology. It should be underlined that the reflection proposed is just at an initial step and, because of the relevance of the case proposed, further research and analysis are needed. The data concerning the materials field are not as precise as they should be, and the social dynamics that lead to the strong level of discrimination of women in the field should be discovered with both qualitative and quantitative means.

It is important to stress that the lack of opportunity for women is not the only process that is worth studying. From the above analysis, it emerges that gender dynamics – even if still "obscure" – strongly characterizes the materials field and the related value chains. Therefore, an important focus of study could be the ways in which research and innovation processes are gendered and the effects that these dynamics have on the materials sector as a whole. It can be stated also that – as some of the scholars quoted above actually do – getting knowledge of the phenomena and processes related to the presence of women in the materials field could produce important and positive impacts on women as well as on the overall economy and society.

Appendix A



Notes: Reference year for Eurostat data: 2007–2012; Reference year for WiS data: 2007–2013; Exceptions to the reference years (WiS): AT: 2007–2011; BE (FR): 2010–2013; BE (FL), NL, FI: 2011–2013; CZ: 2007–2008; DK: 2009–2013; IE: 2008–2012; CY, PT: 2007–2012; EL, MK: 2012; PL, SK: 2012–2013; BA, SI: 2013; HR: 2014; LT: 2007 (She Figures 2012); UK: 2006 (She Figures 2012); Data unavailable for: WiS Grade A, B and C: AT, BG, EE, FR, HU, LU, LV, RO; Eurostat: ISCED 5A Students: LU (2007), ISCED 5A Graduates: FR (2012), LU (2007), ISCED 6 Students: DE (2007), LU (2007), NL (2007), ISCED 6 Graduates: FR (2012), IT (2007), LU (2007), PL (2012);
Others: SET fields of education = Science, maths and computing + Engineering, manufacturing and construction; SET fields of science = Engineering and technology + Natural sciences.

Source: Women in Science database, DG Research and Innovation and Eurostat – Education Statistics (online data code: educ_grad5)

Figure A1. Proportions of women and men in a typical academic career in science and engineering, students and academic staff, EU-28, 2007–2013. Source: European Commission [24, p. 128].

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