Analysing the mitigation actions in the French construction sector related to the circular economy approach: A Waste Input-Output analysis

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Abstract. The building sector has long recognized the decisive role in the main global environmental along the various phases of the building life cycle. This might be a key for the development of mitigation actions in the European's construction sector related to the huge raw material consumption and the construction and demolition waste (C&DW) generation. In this sense, circular economy's principles have strong potential to address these challenges in all European Union countries and specially in France. In this point, the major method of input-output analysis covers waste input-output model (WIO). As the building construction process chain is complex and has lot of related activities and in a preliminary moment it was developed a conceptual model, this approach provided an assessment of the mitigation actions of C&DW generation in French. Results of this assessment showed that among several materials some positive waste reduction can be noticed in the construction process, especially in the concrete, metal, rock/rubble and sand/soil. However, the same study exhibited that even materials that can be recycled in the construction process might not have a positive amount of waste reduction for the demolition site due to the lack of a properly waste separation and contamination during this process, for instance the concrete, plastic and metal.

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1 Introduction

The growth in the worldwide population have been stimulating the urbanization phenomenon and additionally increasing the demand for new buildings, energy efficiency, waste management and mobility. A recent projection shows that the global population is expected to reach between 8.3 and 10.9 billion by 2050 (UN,2012). This increases the society concerns to develop basic infrastructure for all the global population and to control main global environmental issues of the industrial sectors.

The building sector has a decisive role as is responsible, along the different stages of the building life cycle for ozone depletion, water and soil pollution, deforestation and global warming, and is responsible (Rodríguez et al., 2011) due to the elevated natural resources consumption and high waste generation (Gangoles et al, 2007), specially produced during the demolition phase (Jiménez et al, 2012).

Some of these wastes can be recycled and reused, but still most of them are dumped in a landfill. An explanation for this can be found first of all in the waste composition. Wastes are normally the mixtures of inert and organic materials. The inert wastes are often used in public filling areas (road construction for instance) and in the construction site. However, the remaining wastes are often mixed and contaminated, not suitable for reuse or recycling and are disposed in the landfills (Shen et al, 2004).

There are some barriers in the application of circular economy in the construction site and a big part of them are related with the economic costs of respecting the current legal framework and the need of extra time devoted to sorting out waste. Furthermore, the lack of space in the construction site to locate the different types of waste containers and the difficulty on tracking activities of subcontractor's workers can be highlighted (Gangolles et al., 2014, Saez, 2013)

On the other hand, the study of Gangolles et al. (2014) about the factors that motivate construction companies to implement effective waste prevention and management actions in Spain, showed that current legislation, company's public image improvement, costs reduction, increase in the company's competitiveness and health and safety work conditions are important factors that can stimulate construction companies to be more responsible.

The sustainable development of economy has been perceived for the governments and the society as an opportunity to deal with the serious challenge of global warming that represents strong consequences as costly adverse effects (Stern et al., 2006 and OECD, 2008) and environmental pollution concerns.

France is the country of the European Union (EU) with the highest C&DW generation rate. In 2010, the French C&DW generation was about 260.2 million tonnes. This number represents almost 31% of the total C&DW

generation of the EU - about 860 million tonnes (Eurostat, 2014) as is presented in Appendix A. Besides, the recycling rate in France in 2010 was 50% (SOeS, 2013).

This might be a moment for the mitigation actions development in the French construction sector related to the high material consumption and the C&DW generation. The adoption of sustainable construction patterns could be a possibility to attend the requirements of the EU Waste Framework Directive 2008/98/CE (European Parliament, 2008) and the French National Program of Waste Prevention that establish, respectively, that waste valorisation must be increased in a minimum of 70% by weight in Europe by 2020, and that France must implement a circular economy model through a C&DW management, prioritizing recycle and reuse systems and reducing land filling.

Environmental advantages of C&DW recycling where proven by Ortiz et al (2010), evidencing the importance of avoiding land filling. Even if sometimes the environmental impacts of recycling strategies can exceed the environmental benefits, Blengini (2009) affirmed that, for the C&DW, recycling process is "economically feasible and profitable from energetic and environmental point of view".

Waste landfill induces important environmental impacts as water and soil pollution, and the greenhouse gases production, as CO2 and methane, due to the waste anaerobic degradation (Lu et al, 2013). Furthermore, it is the worst of the options for waste final destination because the embodied energy of the materials are not used (Vefago et al., 2013).

Within the new context, this paper aims to contribute to this environmental agenda by the analysis of construction sector intensity shifts in energy and material consumption in France and its consequences on natural resources demand. Therefore, this study aims to provide such an integrated framework, of which the main elements are presented in the material flow quantitative analysis.

2 Method

2.1. Circular flow context

The Passet approach expresses the concept of "insert the economic loop" in the large loop of the biosphere (Passet, 1996). In order to answer this question, it is appropriate to take a holistic point of view. It includes some issues as climate change, resource depletion, desertification, the gap between wealth and poverty, all signals of climate change.

It is difficult to insist on clinging to the myth under the classical economists about the resource abundance (Bourg et al, 2010). It is equally difficult to believe that the "invisible hand of Adam Smith" can get out of this ecological crisis. It even appears urgent to change the economic model, to find a mechanism to control the growth of the materials and energy flows. The circular economy responding to this question try to change the mainstream pathway such as lineal production towards an approach that used a circular material and energy flow in a global anthropogenic system. It is logic to question the ability of the circular economy (McDonough et al, 2008) to propose a shift of paradigm.

In this sense, the shift from a linear flow to a circular flow requires a real change of economic model. In fact, the economy has recently witnessed a paradigm shift in the price of energy and resources. During the twentieth century, they have steadily declined, it expected that in the next century this trend to be reversed, witnessing a constant increase, it means that supply could become a problem major, a source of political tensions. The proprietors of the physical stocks will provide some level of security to nations in the condition of supply that are considered today as property resources of tomorrow. The business model that makes this possible based in the sell services, so that economic actors retain ownership of their products. In fact, the problem can be analysed about two themes, characterising the production and technology in ecological perspectives (O'Connor, 1989); second, the contradiction between the "cowboy economy" such as resource depletion economy working with finite and non renewable and close material and energy flux such as a "spaceship".

In this sense, the shift from a linear flow to a circular flow requires a real change of economic model. In this direction, we have recently witnessed a paradigm shift in the price of energy and resources. During the twentieth century, they have steadily declined, it is expected that for the next century that this trend be reversed and that we are witnessing a constant increase, it means that supply could become a major challenge and a source of political tensions. The proprietors of the physical stocks will provide some level of security to nations about the supply that are considered today as manager of the tomorrow resources. The business model that makes this possible is to sell the services, so these economic actors retain ownership of their products and resources, to contribute to their own future supply and National security.

The second factor to consider is that biochemical loops have beginning and end. We must improve it; manage their inventory, maintaining their value, quality and performance of the ecosystem services. This is one of the biggest differences between the circular approach and the lineal approach or mainstream.

The third important factor is the speed of the circular flow, which is a crucial aspect; a model that works with different materials, operated very slowly. In fact, in the other side of the spectrum the recycling materials have a variable life cycle, such as aluminium cans. In this case, we have a fast flow and slow materials loss.

Returning to the circular pattern, it is important to separate between the extraction processes and production processes. In fact, three quarters of the energy used to manufacture a product is invested in raw material extraction, manufacturing of the object requires only 25% of the total energy. But, environment are being perceived as neither non-scarce, bringing a new question about the distribution justice and climate change.

Inevitably, climate change and scarcity was coming, circular economy should contribute reducing CO2 emissions and the others greenhouse gases, reuse and surrender on the repackaged product market, minimize water extraction and waste generation, and strategies to retain materials.

To provide a critical analysis of the construction recycle level, applied a circular economy framework using the extended version of input-output table proposed by Shulin (2011).

2.2. Circular economy of French construction sector: Insight from Input-output analysis

The work will proceed, in one sense, by the development of mitigation actions in the French construction sector in order to reduce the material consumption and the C&DW generation. On the other sense, for the analysis and comparison between a classical waste input-output (WIO) method and a joint production model.

The review builds on scientifically knowledge in circular economy recognized frameworks to develop a holistic understanding of how the production and consumption process are conceived, despite much of this information appears published throughout an academic literature government agency reports (European Commission, 2014) as input-output database.

In this sense, the multisectoral economic models are one of the most powerful instruments, to faith in the field of economic theory, applied economics to the national accounts analysis.

A whole group of multisectoral models with specific features are often associated with authors as Leontief, Von Neumann and Sraffa. The common element its models can be summarized noting that all models have a classical orientation, in the sense that the issues analysed are close to the works of authors such as the Physiocrats, Ricardo and Marx.

We can classify the I/O models using different kind of units of analysis such as money or physical units as tons of waste. In addition, it is possible classify the type of matrix measuring the interdependencies between sectors of the economy. Usually the table is presented as a square matrix. Several types analyzed are based over physical models.

These models include:

• Leontieff model: This model develop an extension of the traditional I/O taking account the pollution including for one hand, extra rows to show the pollution generated by some sectors, in the other hand including the pollution abatement costs that the proprietors of waste must pay for cleaning the pollution.

• Victor model: Victor (1972) proposed a model that considered a sector-commodity (rows) by commodities-sector (columns) matrix to describe the economic transaction.

• Isard model: This author used the Victor model that not considers the ecological process. The Isard (1967) issues addressed to measure the ecological process. It can be used to quantify the biochemical cycles such as carbon, phosphorus, water.

• Daly model: This structure have four quadrants considering the interaction flows within the economy, flows from the environment to the economy, flows from the economy to the environment and flows in the biochemical cycles. Daly (1968) had a fundamental difference about to Isard model, adopting a configuration as sector by sector or process by process, rather the commodities by sectors used by Isard.

Indeed, it possible to distinguished the physical flows according to their origin (source) and destination (sink). A typical presentation of these flows showed in the physical input-output table (PIOT) a commodity by industry format in physical units i.e. tonnes, Mtep. It is possible to presented the PIOT using two asymmetric tables of inputs and outputs. In fact, the symmetrical input-output table can be expressed in two ways. First, it can give a material flow inter industries (industries by industries flow). Secondly, it can also be expressed by the materials thus give quantitative relation about the material use (material by material flow) (Pedersen et al, 2006).

PIOT not only showed the physical flow of commodities, also it possible to include the waste generation in the model. An example was the method to waste issues is the work of Duchin (1990). In adition, Shulin (2011) suggested an indirect approach of the classical input-output method proposed by Leontieff which examines the change in material flow through the circular economy issue. In this sense, a key to understanding the concept of circular economy is through the study of their material supply. In this sense, we have an available data source on material consumption, which integrated economic and physical accounts of the national accounting, including accounts in France which allows us to explore the raw material evolution of construction sector.

Therefore, and regarding the current political scenario, circular economy's principles have strong potential to address these challenges related to the construction sector, especially when transforming the raw material production and consumption, and in particular, in the French scenario.

Figure1 represents the strategy of C&DW management for the French construction sector scenario implemented by the government in order to attend the 70% of reduction proposed by the EU Waste Framework Directive. The C&DW are valorised through the recovery or recycling process, or incinerated (with or without energy recovery), or are sent to a storage centre (IFEN, 2007).

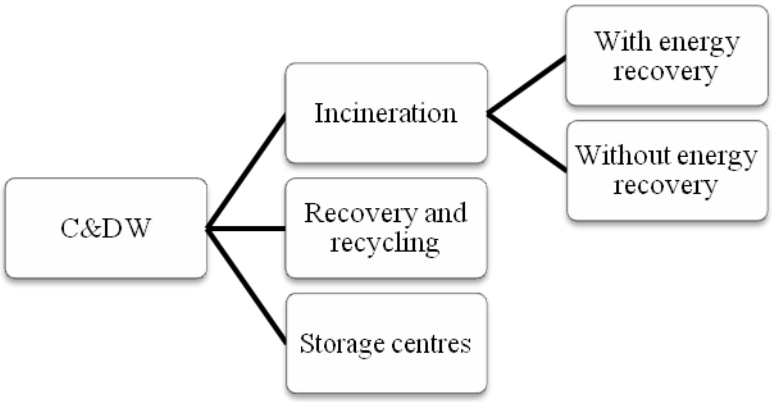

Figure 1. C&DW management for the French construction sector

Source: IFEN, 2007

The Waste Directive n°2008/98/CE (European Parliament, 2008) states the waste prevention act in five main points: prevention, reuse, recycling, valorization and disposal.

Inside this C&DW management, first of all it is assessed the possibility to do the waste separation inside the construction site. If it is not possible, a place for this purpose should be established. The waste separation should be done in different bins, depending on the type of material, to evaluate the destination. These bins could be identified by colour or through a signpost to prevent mixing the different waste types. Depending on the waste it is possible to reuse or recycle. When there is no possibility to reuse or recycle the waste should be dispose in a responsible way.

This study uses the definition of Gao et al. (2001) for the recycled building materials. Goa et al. (2001) characterized as recycled building materials "a material, which can be remade and reused as a building material after the building disassembled".

Recovery or reused materials are materials that did not passed through any chemical transformation. Those materials conserved their internal structure and its physical state, however, does not need to serve the same function as it did in the previous life cycle. The advantage of the reuse process is that it needs less energy to make the material's components suitable for its new functions.

Considering the definition of both process and the needs of French engagement to reduce the waste production in order to attend the European Directive, it is correct to say that reuse came first as a valorisation possibility, followed by recycle, incineration and finally landfill, where none of the energy contained in the materials and components is used (Vefago et al., 2013).

Regarding the information about the C&DW French generation of 2010 it is possible to affirm that 94% of the C&DW generations are constituted by inert waste as show in Table 1. This inert waste has a high potential for reuse and recycle because in general do not require decontamination process and any significant costs are required. Much of inert waste can be reused directly on site or on another operation, besides that this waste can then be processed for reuse in road works (ADEME, 2012).

Waste type	Production in million tones
Inert (soil, rocks, concrete, road demolition materials, glass, construction materials)	243.4
Non-hazardous (common industrial waste, wood, dry wall, metals, plastics)	14.3
Hazardous (aerosols, oil, asbestos, paint, polluted soil, tar and related products, hydrocarbons and other related products, batteries, accumulator, treated wood and any product generated by treating wood, packaging tainted by hazardous products)	2.6
Total	260.3

Table 1. C&DW management for the French construction sector

Source: SOeS, 2014

In France the same inert waste when not valorised are sent to storage centres costing from 1 to 8 Euros/ton (FFB, 2014). For instance, 44% of the C&DW inert (333,3 million tonnes) where sent to the storage centres, in 2004, representing an annual approximate cost for the government (considering the cost to send to the storage centres 4 Euros/ton) 1,34 billion Euros (IPHEN,2007). This value could be reduced 40% to 50% with a proper

C&DW management implementation. Besides that, almost 6% of the C&DW French generation is represented by non-hazardous waste that includes materials as plastic, metal, wood and dry-wall that have a big valorisation potential, as well.

Considering the evaluation systems available about the material flow, it is correct to say that most of these systems measures the level of recycling economy and material flow of non-hazardous materials as metal (UNEP, 2011; Wallsten et al, 2013) or plastic based on indicators system.

With the application of sustainable development theory, it is possible to identify big opportunities to use a circular flow approach in the waste management in France, and specifically, in the Île-de-France (District of the Paris Region). On the one hand, it has being recycled 10% of gypsum, 4% of PVC. On the other hand, it has not being recycled the glazing of 1.5 millions windows and 4 millions of square meters of carpet tiles each year (IUA îdf, 2014) that are potential inert waste that should be valorised.

All this information, aligned with the significant amount of the French C&DW generation and the legal framework represent together a convenient scenario for the construction material's circular flow.

Under the circular economy model, resources are used with higher efficiency and the possibilities for reuse and recycle are considered crucial in order to minimize pollution and anthropogenic waste (Chen et al, 2012; McDonough et al, 2008; Ellen MacArthur Foundation, 2013).

2.3. Introduction to the waste input-output (WIO) approach

There are many assessment methods based on specific indicators for sustainable construction practices (Horvath et al, 1998; Ferández-Sánchez et al, 2010; Mateus et al, 2011; Wiedenhofer, 2014) and besides that, life cycle assessment (LCA) (Graedel, 1998; Scheuer, 2003) and the environmental certifications are important tools that assist people to indentify environmental improvement opportunities. However, in order to understand the factors that influenced the intensity shifts in material consumption and the mains impacts, waste input-output approach (WIO) was used.

In the current study, the main method of input-output analysis covers WIO (Nakamura et al, 2002, 2009) linked with a circular economy assessment. Input-output analysis is one of a set of related methods which shows the relation between the commodities and the industries. The WIO is a hybrid methodology of LCA that take in charge all the phases of life-cycle, production, use, and End of Life (EoL) (Shulin Li, 2011). This method is very effective as a tools of waste management and is widely used in various countries as China.

2.4. The calculation of benefit contribution rate of recycling economy

The residuals of production processes called pollutants have been traditionally treated in the economics literature for the theory of the externalities by Pigou through the costs or benefits of activities "spill over" (Pigou, 1920). However, only effects of some types of waste, for example the demolition waste, may usefully be consider as ‘public interest’. This work aims to adapt the input-output model, with an emphasis on empiricism. Material flow and waste can be conveniently included in input-output model based in waste accounting identities (Victor, 1972). These can be subdivided into raw material (metal, wood, paper, plastics, concrete, rock, sand, glass, tile) and main processes (construction, demolition, general civil and renovation).

	Construction	Demolition	General civil	Renovation	Waste	Output waste
Metal	z_{ij}	z_{1j}	$\cdots$	z_{nj}	W_j	OW_j
Wood	z_{i2}	z_{2j}	$\cdots$	z_{n2}	W_2	OW_2
Plastic	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Paper	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Concrete	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Rock/rubble	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Sand/soil	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Glass/tile	$\vdots$	$\cdots$	$\cdots$	$\vdots$	$\vdots$	$\vdots$
Others	z_{in}	$\cdots$	$\cdots$	z_{nn}	W_n	OW_n

Table 2. Waste Input-Output model for the construction sector

Source: Shulin Li, 2012

Table 2 sets the WIO model for the construction sector where the data on construction sector may be used to calculate the coefficient of waste cumulative reduction. In other words, Table 2 establishes a circular economy framework for the construction sector.

The general intent of constructing the WIO model and the attendant analytical tools is to better understand the flow material inside the construction process. For this purpose, the waste reduction in each construction stage were studied. This paper uses the coefficient of waste cumulative reduction (Shuli, Li, 2011).

$$a_i = \frac{\sum_{j=1}^{n} z_{ij}}{OW_i} \quad i, j=1,2, ...,n \tag{1}$$

a_i is the waste reduction rate within the construction material (metal, wood, paper, plastics..) in waste total output.

In addition, we would define a specific case of a_i. It defines the waste direct reductions a_i within the main production stage, so it is,

$$a_{ij} = \frac{z_{ij}}{OW_j} \quad i, j=1,2, ...,n \tag{2}$$

a_{ij} is the waste reduction rate within the main production stage *j* in per unit waste production of the construction material *i*.

Using the traditional input-output method (Leontieff, 1960). The paper defines *A* (the direct reduction coefficient matrix) and *B* (the complete reduction coefficient matrix) knowing that *B* indicates the waste complete reduction coefficient within the construction material *i* in the stage *j* (Shuli, Li, 2011).

$$A = \{a_{ij}\} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{00} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \qquad B = \{b_{ij}\} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{00} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} = (I - A)^{-1} - I \tag{3}$$

Where, *B* indicates that amount of waste can be reduced directly or indirectly reduced of the raw material *i* in the main production stage *j*, Defined b_j as the benefit contribution rate of recycling economy. If $b_j \rangle 1$ through the mode of circular economy (Shuli, Li, 2011).

$$b_j = \sum_{i=1}^{n} b_{ij} \quad i=1,2, ...,n \tag{4}$$

2.5. The circular economy in the construction: a special case of joint production.

In the last section, we have analysed the circular economy issue using a commodity-by-industry models proposed by Isard (1968), Victor (1972) and Stahmer (1996). This model presented the interactions between the environment and the economy. A physical Input-Output (PIOT) framework has been analysed following the physical flow, the commodities through the processes required by fundamental thermodynamics (O'Connor, 1993) and non joint production.

Transformation activities of processes bring out distinctive properties of the mass-closed "Space-Earth" (O'Connor, 1993). In the Sraffa tradition this issue has been presented through a set of interdependent production processes. Inside the thermodynamic considerations, it is possible to distinguish between construction materials as concrete and paper, which have a large recycle rate, and the other, with a small recycle rate (see Table 4).

In an explicit representation, a joint production model in the construction sector using recycle consideration is explored. An angle of attack proposed by O'Connor (1993) to expose a joint production model will be used. Let us consider some definitions about the model.

a) The model is composed of a set of interdependent production processes, for algebraic convenience, assumed that the number of processes is equal to the number of commodities.

b) Material resource inputs and outputs are constants during each period, are allocated using the same technologies for the ensemble of process.

c) All resources appearing as inputs and are allocated in the end of the period.

d) All commodities have the same rate of return.

It is intended to establish a model to give some formal concepts. In matrix form, $A\text{p}\,(1+\pi) = B\text{p}$, using Sraffa's terminology, it is presented the material resource inputs (A) and outputs (B). The relations of value can be know solving 'p' (commodities prices) and 'π' (rate of return) see O'Connor (1993).

Suppose a generic system with 3 distinct production processes (D, M and W) and 3 distinct types of resources (d, m and w) as inputs and/or outputs.

- Process D: An ecological process which functions to reproduce the ecological capital (resource d - wood). It means to take the forest as simply self-reproducing.
- Process M: An economic process which uses an economic capital good (resource m, for example the concrete), along with an ecological capital good (resource d - wood) as a raw material to produce more economic good and an economic waste product (resource w- construction waste).

- Process W: A waste disposal process which recycle an economic waste product (resource w- construction waste), to produce an ecological capital good (resource d - wood) and an economic capital good (resource m, the concrete).

Let us to show the model, the matrices for *A*, *B* for the tree-process, tree-resource model have the structure:

$$A = \{a_{ij}\} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & a_{mm} & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad B = \{b_{ij)}\} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & b_{mm} & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{5}$$

Throughout the industrial economy is represented by the inputs a_{mm} and outputs b_{mm}. In fact, the process M can be represented trough the inputs as a_{md} which come from the environment; this can be considerate as 'free goods', at the same time, this waste can be presented as waste in outputs b_{mw}.

$$A = \begin{bmatrix} 0 & 0 & 0 \\ a_{md} & a_{mm} & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & b_{mm} & b_{mw} \\ 0 & 0 & 0 \end{bmatrix} \tag{6}$$

The structure given in (6) can be modified using the b_{wm} in (7) as a waste construction material that can be recycling knowing that some waste can non-recyclable. But In this current pathway, the study will be limited on recyclable waste. The waste input can be presented by a_{wm} and a_{ww} in (8).

$$A = \begin{bmatrix} 0 & 0 & 0 \\ a_{md} & a_{mm} & 0 \\ 0 & 0 & a_{ww} \end{bmatrix} \qquad B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & b_{mm} & b_{mw} \\ 0 & b_{wm} & 0 \end{bmatrix} \tag{7}$$

Using these changes, the outputs were redefined trough the rate of recycling. For example, the b_{ww} defined recycle outputs and the b_{**} as non recyclable. If it is recycled or recovered, the waste to put into the economy is defined by $a_{ww.}$. Related inputs should be divided in two parties; first party showed the recycling waste that can be recover as a_{wm} and the second party presented non recyclable waste as a_{**} that must be stocked.

$$A = \begin{bmatrix} 0 & 0 & 0 \\ a_{md} & a_{mm} & 0 \\ 0 & a_{wm} & a_{ww} / a_{**} \end{bmatrix} \qquad B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & b_{mm} & b_{mw} \\ 0 & b_{wm} & b_{ww} / b_{**} \end{bmatrix} \tag{8}$$

The recycled waste can be valorised with a « positive value » in the economy. However, the non recyclable waste must be stocked. In this case, it the stocker or compensation cost can be considered. This cost can be pay for the proprietors of waste to compensate this pollution.

$$A=\begin{bmatrix} 0 & 0 & 0 \\ 0 & a_{mm} & 0 \\ 0 & a_{wm} & a_{ww} \end{bmatrix} \qquad B=\begin{bmatrix} 0 & 0 & 0 \\ 0 & b_{mm} & b_{mw} \\ 0 & 0 & 0 \end{bmatrix} \qquad (9)$$

In addition to the "free" and "costly "disposal (O'Connor, 1993), the same processes M can be used with some dangerous throughput of waste as b_{mw} see (9). It is possible to recycle a_{ww} in the fact, that the proprietors of dangerous waste pay a "negative price" for the pollution actions on *A* to compensate the waste disposal processes in *B*. The distinctive considerations of joint production waste disposal in a circular economy context will be discussed in a next paper.

2.6. Data Collection

The core construction materials are concrete, metal, wood, sand and the other (see Table 3). We choose these materials as the accounting the waste reduction.

In order to solve this waste reduction; data were mainly collected from the French Institute for the Environment (IFEN). This data was adapted using the percentage of construction waste composition published by Hong-Kong city (Li-yin Shen, 2009) (see Table 3).

Material type	Millions of tons			
	Demolition site	General civil work	Construction site	Renovation work
Metal	1,25	14,63	0,03	0,68
Wood	1,56	20,48	0,00	0,68
Plastic	0,62	8,78	0,00	0,68
Paper	0,62	5,85	0,00	0,14
Concrete	23,40	204,75	1,28	9,45
Rock/rubble	0,62	2,93	0,16	0,00
Sand/soil	1,56	0,00	1,28	0,00
Glass/tile	0,94	5,85	0,00	1,35
Others	0,62	29,25	0,16	0,54
Total	31,20	292,50	2,91	13,50

Table 3. Waste of French construction sector

Source: IFEN, 2007; Li-yin Shen, 2009

Despite the fact that recycle rate depend of type of building side, construction technologies and the others factors. We used standard recycle rate for each tape of material (Table 4) to calculate the waste reduction amount related with the circular economy issue.

Material Type	Recycle rate
Metal	10
Wood	7
Plastic	2
Paper	60
Concrete	60
Rock/rubble	44
Sand/soil	44
Glass/tile	60
Others	60

Table 4. Recycle rate of French construction sector

Source: IFEN, 2007 Ademe, 2010

3. Results and discussion

3.1. Case study on the construction sector and data collection

The qualitative evaluation model that describes the waste output categories, exchange and releases in the production and the consumption during the building construction process will be established based on (WIO) tools. This study considers that the construction process is divided by fourth main activities: construction, demolition, general civil work and renovation work. The main waste type contemplated were: metal, wood, plastic, paper, concrete, rock/rubble, sand/soil, glass/tile. The WIO represents the interdependence between the flow of goods and the flow of wastes in the construction process.

The calculation results of the WIO model were made considering tree group of construction materials, this path permitted to be a squares matrix. In fact, using this matrix we solved the linear system of equation founded (the material i in the processes j) as the rate of recycling economy.

“The specific meaning of the amount of waste can be reduced directly or indirectly on all production sector while per unit of waste output produced in the production sector j.”(Shulin, Li, 2012)

In the first group (see Figure 2) studied, the construction materials data are composed by metal and glass/tile, wood and paper, concrete, rock/rubble and sand/soil and the other material, that are all presented in the Table 3. The results showed that the amount of concrete waste reduction in the construction site and renovation work is positive, regarding the model of circular economy model. This can be explained due to the waste management systems that have been implemented in the French construction sites in order to decrease the amount of concrete sent to the landfill and the costs related to this. This concrete is recycled and used in as road construction materials for example. The mix between rock/rubber and sand/soil had as well positive results and can be used in the same sector in order to decrease raw materials use. However, the amount of waste reduction of concrete, rock/rubber and sand/soil in the demolition site calculated is negative. This occurs because in the demolition processes there is a lack of waste separation due to the difficulty in isolating the inert waste from the non-inert waste. For instance, this happens in the demolition process of gypsum waste with concrete and concrete walls with the presence of second work elements such as wood and plastic (IFEN, 2007).

For the second group (see Figure 3) studied, the available construction material data were aggregated in plastic, wood, paper and metal, concrete, rock/rubble, sand/soil, glass/soil and the other material of Table 3. Interestingly, the result for the 'paper and wood' in the general civil work are negative, indicating a 'non circular economy' in the Figure 2 and Figure 3.

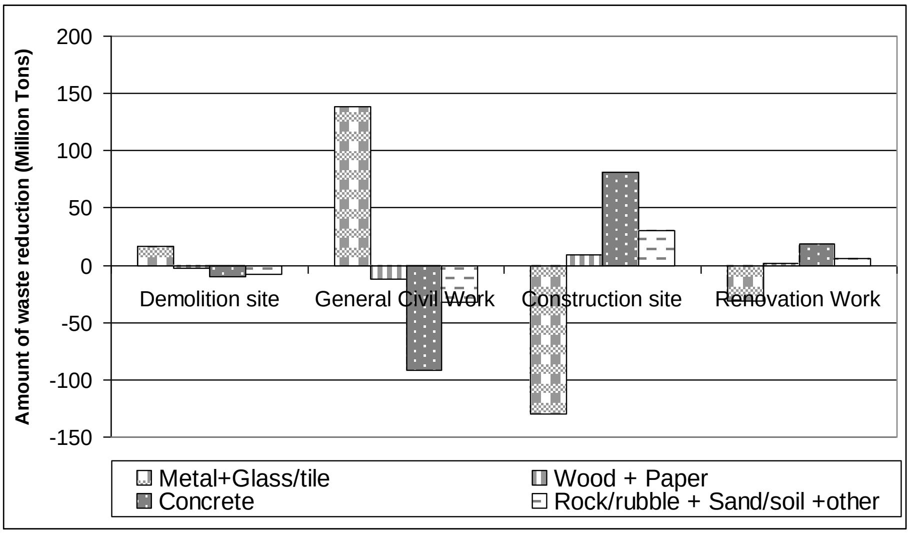

Figure 2. First group of the French construction material

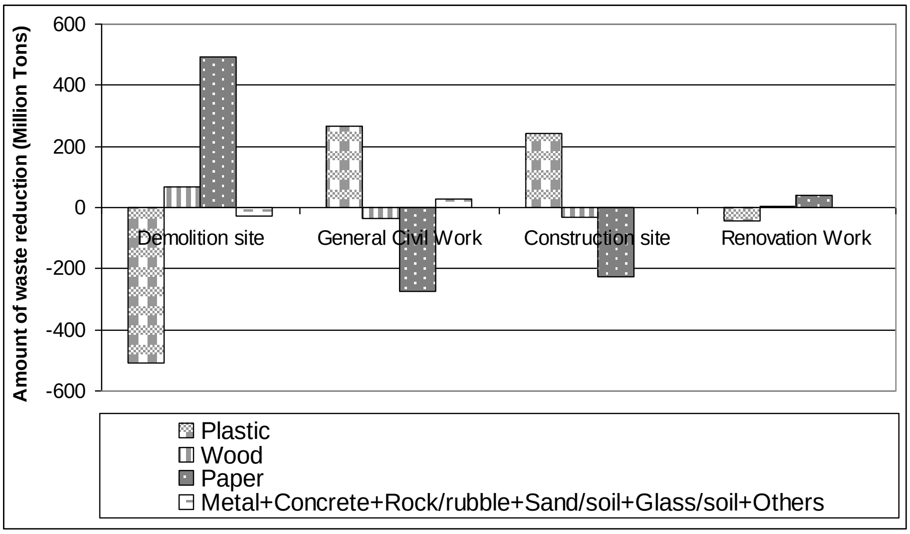

Figure 3. Second aggregation of the French construction material

However, our current results estimates that 'wood and paper' in the demolition site are relatively high and have positive amounts of waste reduction (see Figure 3). This occurs because, 'paper and wood' are potential materials that can be valorised with an optimization of materials separation. The wood can be recycled to create the chipboard and the paper pulp, or can be used for energy recovery in industrial boilers equipped with flue gas treatment system. The paper in the demolition site is positive due to the small amount of this material in the demotion site.

Even with a big amount of concrete waste during the demolition site, there was not significant amount of plastic waste reduction can be found in the general civil work and construction site activities. Through the material recycling, plastic can be included in the composition of finished products (trash bags, pipes, profiles, cans, containers). However, even with big advantages in recycling plastic, in France, as showed in Table 4, there is a low recycle rate for the construction sector. Regarding this information, it is possible to affirm that the plastic in the construction sector (PVC), in France, are not mainly recycled, and in general are transformed in energy recovery. Nonetheless, plastic from the demolition site did not represented a big amount of waste reduction because normally they cannot be valorised due to the high contamination rate by dangerous materials.

For the third group (see Figure 4) analyzed of data construction material, showed rock/, sand/soil and glass/tile, metal and the other material from Table 3 were grouped. The results are showed in Figure 4.

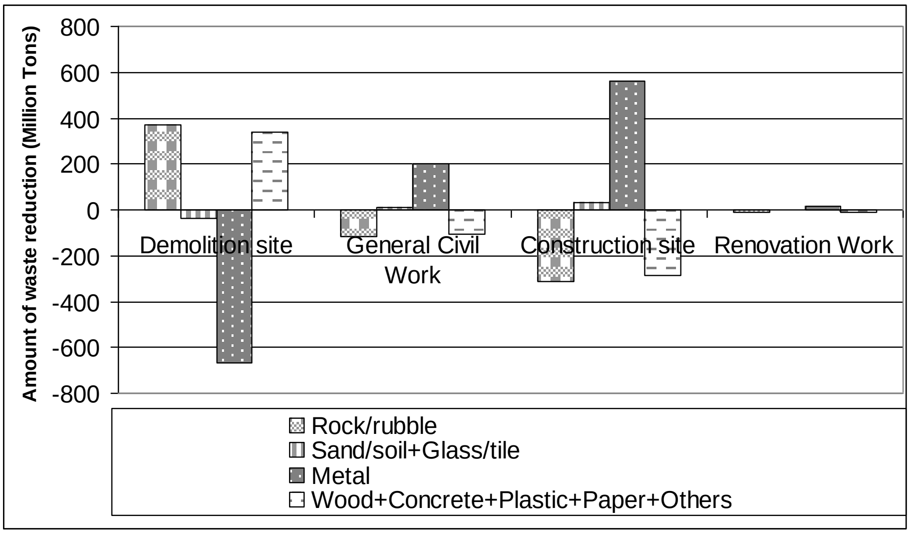

Figure 4. Third aggregation of the French construction material

In the case of demolition site 'rock/rubble, sand/soil and glass/tile' it is correct to affirm that there is a significant amount of waste reduction through the model of circular economy. Sand and soil are valorised and can be used in the same construction site for earth working or as a road material (IFEN, 2004). Glass can be recycled, specially the glass windows, that can be used to manufactured glass bottles. Tiles can be recycled as well. Both can be valorised since are free from dangerous substances (Vefago, 2013). Metal can be melted and recycled, and used in metallurgy and steel industry in almost all the construction activities, however for the demolition site the amount of waste reduction is negative due to the presence of dangerous substances that disables the valorisation process.

4. Conclusion

Inside the urgent worldwide scenario of EU Waste Framework Directive 2008/98/CE (Europe, 2008) and the French National Program of Waste Prevention that establish, respectively, that waste recovery must be increased to a minimum of 70% by weight in Europe by 2020

This study applied the input-output model to the construction sector using a combination of various approaches. In the present case, environmentally extended input–output analysis has been combined with circular economy issues in order to evaluate the French construction situation.

This paper extended the way of assessing the relative sustainability of material flow in particular construction commodities and process from the point of view of resource use and waste generation. The research can be disaggregated into the following three steps: a physical input-output table of eight commodities and fourth processes has been created, linking the amount of physical flows with the recycling possibilities. Then the data has been aggregated in matrix squares of fourth commodities by fourth processes, employing the approach proposed by Shulin (2011) to the development of a circular economy index. The method permits to compare each construction material with the other inside a sustainability point of view.

The application of this method showed that, in France waste management processes are specially been implemented inside the construction and demolition site. For the construction site it is possible to note a positive circular economy for concrete, metal, rock/rubble and sand/soil. However, during the demolition site, the circular economy is negative for concrete, even with the big amount of this type of material waste during the demolition site, plastic and metal probably due to the lack of a properly waste separation during this process and also due to the presence of dangerous substances that prevent the valorisation process.

Inside the circular economy concept it is evident that waste management has a big importance because without a strategy of waste separation and proper storage in the construction or demolition site, the waste goes directly to landfill, increasing environmental and economical impacts because if the waste can be recycled or reused it is because the waste has its own value.

The paper offered an assessment of the circular economy inside the construction sector in France and also opened a discussion about the government engagement inside the public sector, in promoting actions and decreeing laws to implement a proper C&DW generation in France, but also the business opportunity inside the recycling and the reuse of materials, or for construction site, or other purposes or other industries. This could encourage the development of innovations focused in the subjects, as for instance, the concrete recycling and also can stimulate the society to realize the value of materials waste inside a production chain.

In addition, this paper discussed a theoretical application of joint production in the construction sector, using a square matrix of tree commodities by tree processes. In fact, divided outputs in two parties; first party showed the recycling waste that can be recover and the second party presented non recyclable waste that must be stocked, considering the stocker cost or compensation cost paid for the proprietors of waste to compensate this pollution. Of course, as the complexity and the joint production process, this model still has some flaws and weaknesses, needs further study in the future.

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Appendix A. Waste generation by economic activity and households in EU in 2010

	Total waste from economic activies and households	Mining and quarrying	Manufacturing	Energy	Construction & demolition	Other economic activities	Households
EU-28	2 505 660	671 830	275 960	86 040	859 870	392 360	219 600
Belgium	62 537	1 701	14 543	1 210	18 165	22 239	4 679
Bulgaria	167 396	150 214	3 306	8 032	79	2 235	3 529
Czech Republic	23 758	115	4 202	1 540	9 354	5 212	3 334
Denmark	20 965	41	1 919	517	3 176	12 877	2 436
Germany	363 545	24 493	48 981	9 087	190 990	53 682	36 312
Estonia	19 000	6 453	3 716	6 534	436	1 430	430
Ireland	19 808	2 196	3 259	334	1 610	10 679	1 730
Greece	70 433	44 793	4 941	11 029	2 086	2 387	5 198
Spain	137 519	31 732	16 480	2 339	37 947	25 823	23 198
France	355 081	1 053	20 382	993	260 226	43 121	29 307
Croatia	3 158	29	634	108	8	2 379	0
Italy	158 628	706	35 928	2 660	59 340	27 515	32 479
Cyprus	2 373	382	132	3	1 068	327	461
Latvia	1 498	1	375	25	22	382	694
Lithuania	5 583	7	2 653	68	357	1 238	1 261
Luxembourg	10 441	18	867	2	8 867	437	250
Hungary	15 735	87	3 134	2 718	3 072	3 859	2 865
Malta	1 353	57	9	0	988	150	150
Netherlands	119 255	184	14 094	1 156	78 064	16 685	9 072
Austria	34 883	269	2 958	453	9 010	17 569	4 623
Poland	159 458	61 547	28 618	20 291	20 818	19 294	8 890
Portugal	38 347	1 206	9 766	456	11 071	10 386	5 464
Romania	219 310	177 404	7 862	5 888	238	21 791	6 127
Slovenia	5 159	12	1 517	558	1 509	835	728
Slovakia	9 384	166	2 669	878	1 786	2 167	1 719
Finland	104 337	54 851	15 211	1 445	24 645	6 504	1 681
Sweden	117 645	89 026	7 823	1 479	9 381	5 898	4 038
United Kingdom	259 068	23 092	19 970	6 239	105 560	75 258	28 949
Liechtenstein	312	12	32	0	0	268	0
Norway	9 433	366	2 687	28	1 543	2 580	2 229
FYR of Macedonia	2 328	855	1 017	4	0	0	451
Serbia	33 623	26 458	1 146	6 019	0	0	0
Turkey	783 423	723 791	11 406	18 578	0	60	29 587

Source: Eurostat (online data code: env_wasgen)