Monitoring circular economy in the building sector: prospective work on btpflux and its extended functionalities

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Abstract:

The building sector is challenged by an increasing demand for effective waste management and resource utilization to mitigate the environmental impacts, particularly contributing to climate change. This underscores the necessity of enhancing circular economy (CE) practices into the building sector by introducing more reuse and recycling into the end-of-life (EoL) management of building products. Building upon BTPFlux, a building material flow analysis model, designed by the Scientific and Technical Centre for Buildings (CSTB), the present study investigates how to better estimate the reuse potential of buildings within a given territory. The study proposes extensions to BTPFlux to integrate circularity indicators enabling a better characterization of material flows within a territory. This set addresses the difficulties of adapting for specific territories, giving them more visibility on the material flows within and enhances their comprehension. It also enables new functionalities: a decision-making platform facilitating the circularity of product for a group of actors, allowing them to pilot more easily. By quantifying material flows, identifying circular economy opportunities, and assessing impacts, stakeholders can tailor strategies to meet specific challenges and goals effectively. This research contributes to advancing circular economy practices in the construction sector and supporting sustainable development at the local level, exemplified through the Paris-Saclay case study.

Keywords: Circular economy, Construction sector, material flow analysis model, Product Equipment Material Waste, Functionalities

1. Introduction

1.1. General context

The construction sector is one of the biggest raw material consumers bringing by significant damages to the environment. For example, 40 Bt of sand, mainly used for concrete manufacturing, is consumed every year worldwide, putting an important pressure on this material and jeopardizing more than 75% of global beaches by 2035. Moreover, in less than a decade the global built surface has increased by 11% and important investments were made. Such pressure on natural resources is accompanied by an increase of greenhouse gas emissions. In 2021, the construction sector represents around 39% of greenhouse gases (GHG) emissions and 36% of the energy consumption[1].

In France, with an annual tonnage of construction material estimated to 394Mt in 2021[2], the sector is currently facing 3 major challenges:

- The need to create **sustainability** along the complex and multi-actor supply chain.
- The creation of a **resilient raw material source**, less sensitive to supply rupture.
- The obligation to reduce its impact on the environment to meet the French government's commitment to **carbon neutrality** by 2050.

These challenges are followed by objectives defined by the French government, described in its national low carbon strategy [3]:

- **Reduce** GHG emissions to 49% between 2015 and 2030.
- **Reduce** waste sent to landfill by 50% between 2010 and 2025.
- **Generalise** source separation of bio-waste with a view to recovery by 2025.
- Recycle 65% of non-hazardous waste by weight (55% by 2020) in dedicated valorisation sectors.

To tackle these challenges and fulfil these objectives, Circular Economy (CE) is a promising alternative to the produce-use-dispose paradigm. In fact, waste generated by the building sector has reached 43Mt in 2021 [4], most of it being used to fill quarry or disposed into landfill, the sector faces both the need to deal with an enormous quantity of waste, and secure its supply chain to ensure its consumption, while also taking into account its GHG emission reduction. Hence, enhancing waste management circularity seems like a good opportunity to reduce both raw material pressure and carbon emissions inherent to the construction. Such new policies could as well contribute to meeting the French Governments' objectives such as preventing waste generation, promoting re-use, and better inform both consumers and actors of CE [5] [6].

In this national context, the Responsabilité Elargie des Producteurs des Produits et Matériaux de la Construction et du Bâtiment (REP PMCB), introduced in 2023 [7], aims at structuring waste treatments and recovery sector. It also sets ambitious target for material recovery from the sector to contribute to its circular enhancement and reduce its environmental impact. PEMs re-using incentives have not been proposed so far. Although reusing can be a promising alternative for the end-of-life management of construction waste and has less environmental impacts, it needs a finer and extended understanding of the deposit, thanks to new technologies such as BTPFlux, than waste management. It considers the components (doors, windows, pipes...)of the building rather that its constitutive materials (concrete, metal, stone...), valorisation sector needs to strengthen and decide which valorisation is the best for each component (re-use, recycle, repurpose…).

1.2. Territories definition

A territory comprises various physical characteristics: actors, infrastructures, populations, frontiers, material, and energy flows. Working on circularity on a territorial scale allows the creation and activation of multiple actors' synergies and networks, the creation on valorisation sectors and more economic opportunities, harmonized policies across multiple localities, leading to more strategic and impactful initiatives. A territory has also more intangible characteristics, its political context, intrinsic interactions, history, interactions with other territories, reaching sometime out of its physical frontiers. In the PEMW management sense, a territory still needs to be understood, analysed, and characterized.

In this regard, when a territory aims to introduce a policy, e.g., increase circularity of PEMW, all these direct and indirect impacts need to be considered conjointly. In fact, enhancing PEMW circularity requires : (1) identifying stakeholders that may have a role within the development of CE activities, (2) characterizing material flows within a territory, (3) studying interactions between territories where material flows can be exchanged, and (4) determining the value-added for local populations and in terms of the environmental impacts' reduction.

1.3. Stakeholders identification

Among the stakeholders that can be potentially involved or can benefit from more circularity:

- Territories, to pilot both their PEMW stock and circularity by developing local activities and businesses, fluidify their stock and minimizing PEMW time storage.
- Project owners, to establish strategies and better plan construction & demolition activities, find new and cheaper construction material nearby.
- Construction project managers, to know if PEMW are available, when, where, and at what price, secure their supply chain with local stocks.

The emergence of new recovery methods, associated with PEMW circularity enhancement, will probably modify the current value chain. While new stakeholders can see their roles created as enablers, other existing ones will be awaited to adapt. Hence, it is needed to investigate the stakes that can derive from such modification of the value chain.

1.4. Research questions

All the objectives set by the French Government in term of circular economy, waste management, and stakeholders' involvement have raised several questions:

- **What are the needs in term of circularity for territories?**
- **How to give the stakeholders more visibility on the opportunities and risks associated to the PEMWs territorial flows?**
- **How to efficiently advise territories when it comes to activate levers, loosen brakes to develop its circular economy?**

Potential responses to these questions are discussed in the coming sections. The next paragraphs seek to sketch the potential pathways to answer the above research questions considering the existing literature.

2. Method

2.1. BTPFlux presentation

To enable PEMW circularity improvement within a territory, characterizing input and output material flows are key to support the decision-makers, more visibility on the future stocks could help a project owner to secure it, or to shift its construction materials if it identifies an important stock in the coming years of the project. Material flow analysis (MFA) is one of the most appropriate techniques for characterizing regional material flows [8]. In this regard, a model named BTPFlux, developed by the Centre Scientifique et Technique du Bâtiment (CSTB) [9], is in the focus of this research work.

BTPFlux is an MFA model, specific to the current built stock in France, more specifically to the French metropolitan territories. It aims at quantifying and discretizing these PEMWs evolution flows from deconstruction and renovation to better understand and anticipate them. BTPFlux model is structured as follows. The model is designed to operate on the scale of French metropolitan territories. Many different types of territories can be studied, from a national scale to a group of municipalities. Every estimation is made at the chosen territory scale, by considering local particularities, like the building architecture, repartition by usage and construction period. The specific dynamic of deconstruction and renovation are also considered to provide accurate estimations of the territory flows. To provide materials flow estimation, BTPFlux first need to estimate the current built stock crossing several databases, then determine its PEMWs flow dynamics by applying the identified stock renovation and deconstruction rates calculated from the consecutive years in the databases.

After the choice of territory, BTPFlux estimates the material-built stock. To do so, it first extracts the building's characteristics such as its typology, its energetic class from the National Building database (BDNB), it contains various data, including the energy performance indicator, the year of construction and the main use for each of the 20 million residential and commercial buildings. It is constructed by geospatially cross-referencing around twenty databases from public bodies [10]. The second step is about cleaning and enriching this dataset, to determine characteristics such as building area, floors number, to better estimate the materiality. Then only best-defined buildings, with all needed characteristics, are selected in a sample. The materiality of those buildings is then computed using TyPy, another numeric model developed by the CSTB. TyPy is dedicated to the estimation of building materiality using few information on buildings. To perform this estimation, TyPy contains a specific

database of more than 400 generic components (e.g., doors, walls, insulation, and windows). The components quantity present in a building is determine using association and sizing algorithms.

After this built-stock estimation is done, BTPFlux determines the dynamic of the stock. To do so scenarios of build-stock changes are used to estimate the quantities of components generated and consumed by construction sites. The quantities PEMW are deducted directly from the quantities of components, the PEMW composition of each component being in the TyPy database. To do so, Typy algorithm, thank to data extracted from the BDNB, determines the components & macro-components in its own database that make up the building. It then estimates the quantity of these components using the building topography, and the construction period methods. The PEMW flow that can be valorised is then estimated, analysed, and characterized using Sankey diagrams to follow their evolution. The BTPFlux structure is illustrated in figure 1.

The ambition of the study is to provide new circularity indicators to help local authorities and the construction industry improve the sector's circularity at different territorial scales. It aims at giving feedback on circular economy policies' impact on the PEMW flows.

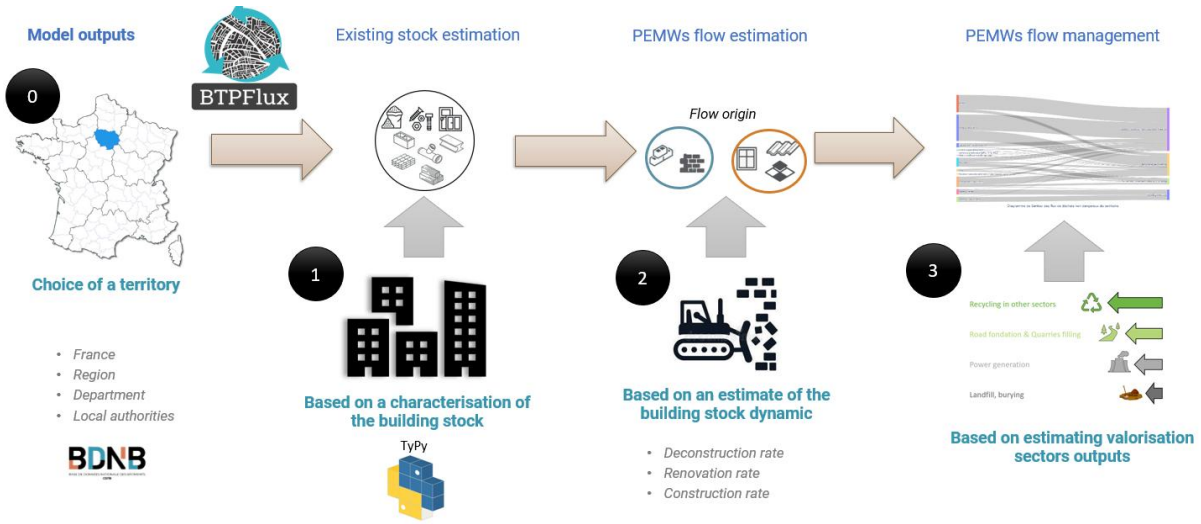

Figure 1 BTPFlux model scheme

2.1. Design of a new set of circularity indicators method

To understand the issues faced by a territory, to evaluate its specific context, and to characterize stakeholders' impacts on circularity, the creation of a set of circular economy indicators specific to the management of PEMW seems effective.

While a significant number of studies have proposed and analysed circularity indicators and different level (micro, meso, macro) so far [11], but so far it seems like PEMWs-focused circularity indicators designed for the actors of the building sector are lacking [12]A method is proposed to list the existing and used macro-indicators, precisely understand, and analyse the state of the art in term of circular indicators at territory level. Add the proposals of the circular economy researchers will then open the set to what is currently done and investigated. Develop new indicators and complete the existing one to finish the set, including the materiality centred indicators that could be calculated with BTPFlux is the last step of the set creation. The obtained set will need to be refiner, optimize, reduced to its most effective, pertinent version, the method is proposed in fig.2.

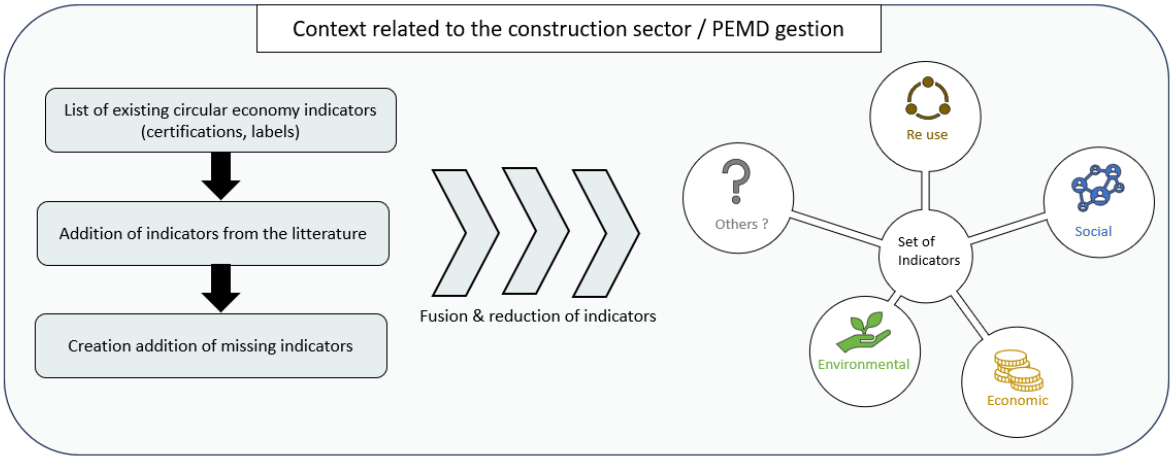

Figure 2 Proposed PEMW reuse specific circularity indicators set generation method.

The first step of the method, aiming to look on what type of indicator has already been not only created but is already implemented by the territories, has highlighted few indicators such as reuse potential, domestic material consumption and the recyclability of materials[13]. So far, indicators developed by the public organizations such as ADEME [14] have shown that among the 35 indicators proposed, only few of them tackles the issue around the building sector materiality.

The second step, looking at pertinent indicators from the scientific literature that are not yet implemented nor finally discussed will be characterised. To do so a literature review will be performed, with a defined taxonomy to select as many pertinent indicators as possible. The number, type of sets and its taxonomy are yet unknown.

At this final step, the list of indicators should be limited to already existing indicators, whether from the public organization and stakeholders, or from the scientific literature proposed sets. However, so far, only few reviews of the existing indicators have been explored. This step will allow the design (potentially with stakeholders) of new indicators to allow the measurement of new impacts that could not be tackled in the previous indicators. These impacts will need to be formulated, analysed, and characterized to develop indicators as precise and relevant as possible, tailored to stakeholders' needs. To do so BTPFlux flow analysis will be expanded to identify and calculate dynamic indicators that will be used in prospective scenarios. Having these indicators seems necessary to understand the levers to be pulled, the brakes to be loosen, to pilot PEMW circular economy at a territory scale and measure its efficiency. They finally aim at being implemented in a platform, designed to enhance the visibility on the materiality. These indicators aim at being used in a platform, giving more visibility on material stocks within the territory and easing the decision-making.

3.2 Impact of the desired platform

The objective of the desired platform is to help manage circularity at the territory scale, it will be done through several major stakeholders. From a report published [15] by the CSTB and ORÉE group [16], three group of actors where identified, and presented in fig.4, the list of stakeholders per group is represented in tab.1, as well as the aims of the platform, and the indicators to achieve them:

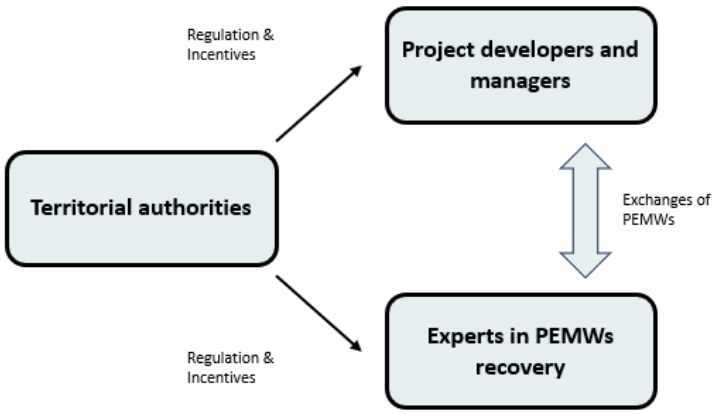

Figure3: Interaction between groups of stakeholders within a single territory

Group of actors	**Added value of the platform**	**Type of indicators**
Project developers and managers	- Secure territorial stocks to ensure security of supply -Facilitates compliance with environmental rules	- Resource criticality index - Resource availability index
Experts in PEMWs recovery	- Allocates their resources (workforces, capacity to deal with)	- Treatment capacity index - Profit and margin indexes - PEMWs fluidity index
Territorial authorities	-Track the flow of materials from deconstruction & renovation - Promote new sectors -Minimize environmental impacts and promote reuse	- Quantity of PEMWs generated - PEMW's fluidity

- **Project developers and managers**, They are composed of projects owners, ordering a project to the managers, hiring companies to build. supported by assistants specialized in circular economy and diagnosticians, they play a crucial role in managing projects within the territory, they are the decision-maker when it comes to deconstruction & renovation action, architectural decisions, building materials management. Insurers also play a role in this group, by ensuring the other actors and delivering ten-year insurances of the buildings. The developers and managers' abilities to effectively manage these projects depends on their visibility of available resource deposits. Better knowledge of resource deposits trough resource availability indexes would allow them to better plan the construction. They will benefit from the platform: resource availably coupled to criticality of the given resource could enable the identification and securing their supplies in advance (such as sand and gravel for concrete), planning adequate storage spaces, and ensuring project continuity.

- **Experts in PEMWs recovery**, both from re-use and waste collection, they collect, transport, treat the PEMWs. These experts such as eco-organizations, marketplaces, waste managers, need to define their workforce and the quantity of waste to be treated to better prepare, they would benefit from indicators highlighting the quantity of PEMWs available, the benefit done treating a given PEMW would bring them stability to develop, strengthening the sector.

- **Territorial authorities**, they define the overall strategy, they oversee the regional planning and the subsidy allocation within the territory. They oversee managing the deposits of components from deconstruction and renovation projects. Their goal is to maximize the flow of these materials to minimize environmental impacts and promote reuse.

This platform will provide near real-time data and analytics, offering a holistic view of resource availability, criticality, and flows. By integrating these indicators into a single platform, stakeholders will have access to valuable insights that facilitate informed decision-making, optimize resource management, and promote the circular economy, potential added values and type of indicators are summarized in tab.1.

3. Conclusion, perspectives and limitations

The construction sector faces significant challenges in managing waste and resources, making the enhancement of circular economy (CE) practices essential. This research introduces BTPFlux, a building material flow analysis model developed by the CSTB, which aims to estimate the reuse potential of buildings within a given territory. By identifying and addressing gaps in construction waste re-use and recycling, the study proposes extending BTPFlux with new circularity indicators tailored to territorial needs. These indicators will provide greater visibility on material flows and facilitate informed decision-making for stakeholders, including project developers, valorisation experts, and territorial authorities. The implementation of these indicators in a comprehensive platform will enhance the overall management of construction materials, optimize resource use, and support the sustainable development goals. The case study of Paris-Saclay illustrates the practical application and potential benefits of this approach, contributing to the advancement of CE practices in the construction sector.

However, BTPFlux model and the proposed circularity indicators need to be continuously updated, so far, the BDNB considers only 2 years of data, both its reliability and the materiality of the excluded buildings are yet unknown. The tool, aiming at being developed to fit all territories, may face difficulties to adapt to one territory to another, since the practices, actors and materials might differ.

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