Dynamic Stock Analysis of Residential Building Materials in the Pays de la Loire Region, France, Using Artificial Neural Network (ANN) Models

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Extended Abstract :

The concept of Urban Mining proposes a transformative vision by considering the built environment as a regional resource mine. It transforms urban space not only into a place of consumption, but also into a strategic reservoir of raw materials that can be recovered at the end of a building's life, following a hierarchy of priorities that favors reuse then recycling of the materials they contain. This approach, rooted in the circular economy, differs from the current linear model, in which materials are extracted, manufactured, used once, and then permanently discarded [1]. It helps reduce the use of virgin resources for the production of new construction elements, preserve the embodied energy already invested, improve sorting and recycling of end-of-life waste, and maximize asset utilization by extending service life or reintroducing materials as new resources [1].

However, the large-scale implementation of these practices is hindered by technical and logistical challenges. One of the main difficulties lies in the lack of short- and medium-term visibility regarding the type and quantity of recoverable materials. Therefore, a combined analysis of material stocks and inflows and outflows represents a crucial challenge for understanding and managing the metabolism of socio-economic systems.

In this context, a bottom-up, building-by-building methodology based on an artificial intelligence model was developed and applied to the Pays de la Loire region in France. This study aims to identify the main material stocks and flows resulting from the deconstruction of residential buildings in order to provide a detailed understanding of the resources available in the territory.

The study led to the development of five artificial neural network (ANN) models to predict the envelope materials of residential buildings including wall type, wall thickness, floor type, and roof type. The French National Building Database (BDNB) was used as the main data source. The BDNB is the most comprehensive building database in France. The database contains a wide variety of information, including building geometry, structure, energy consumption, usage, and many other aspects. The version used in this study is limited to data collected before 2020.

The results show good accuracy, with high correlation coefficients ($R > 0.90$ for some models) and mean absolute percentage errors (MAPE) below 20%, voir le tableau 1. These models were then used to fill in missing data for 488,953 residential buildings in the regional database.

Table 1 : Performance of the ANN models.

Model	Mean Square Error (MSE)	Root Mean Squared Error (RMSE)	Mean Absolute Error (MAE)	Mean Absolute Percentage Error (MAPE) [%]	R
Wall type	1,05	1,03	0,61	9,56	0,92
Wall thickness	11,38	3,37	1,67	6,92	0,90
Floor type	0,19	0,44	0,32	19,44	0,80
Roof type	0,25	0,50	0,30	14,52	0,86

Based on this completed dataset, the total stock of materials in building envelopes was estimated at 92.36 million tonnes (Mt), table 2. Concrete accounts for the largest share (74%), followed by stone and mixed aggregates (14%), brick (7%), wood (2%), and tiles (1%). Other materials, such as slate, steel, zinc, and aluminum, each represent less than 1% of the total stock.

Tableau 2 : Quantity of materials stored in residential buildings in Loire-Atlantique.

	TOTAL	Concrete	Stone & Mixed Aggregates	Brick	Wood	Tiles	Slate	Steel	Zinc & Aluminum
Material Stock (Mt)	92,36	68,4	13,26	6,26	1,83	1,22	0,59	0,74	0,06

Figure 1 illustrates the distribution of material stocks in tonnes per hectare across the Loire-Atlantique map.

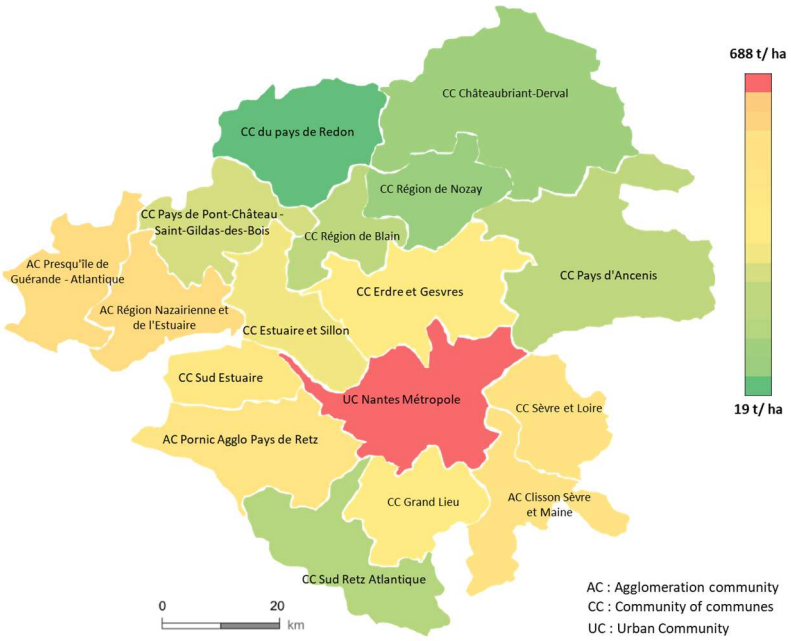

Figure 1 : Estimated distribution of construction material stocks (in tonnes per hectare) in residential buildings of Loire-Atlantique.

A correlation between the cumulative stock and the demographic evolution of the department was developed. Demographic data were obtained from the French National Institute of Statistics and Economic Studies (INSEE) [2], while the cumulative stock was calculated using the model developed in this study. This correlation was established using data from the period 1975 - 2020, assuming that most residential buildings constructed in 1975 were still standing in 2020, with a minimum lifespan of 50 years. This model allows for predicting the cumulative stock over time based on demographic trends (Figure 2).

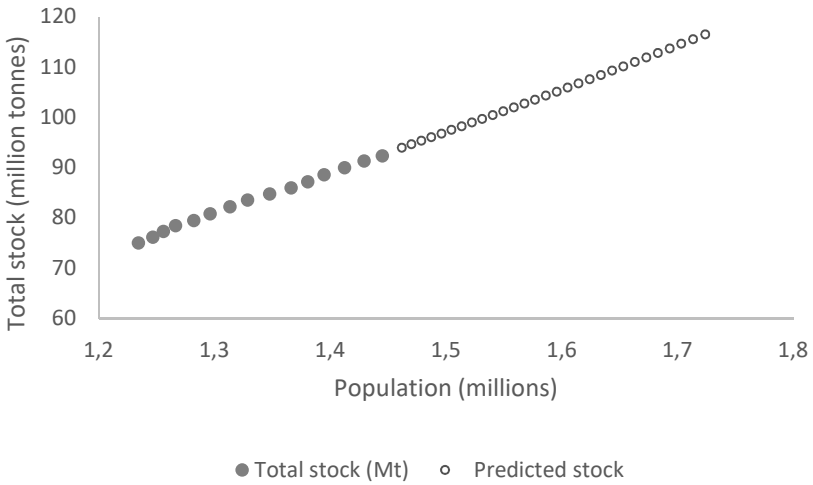

Figure 2 : Prediction of total stock evolution according to demographic growth scenarios.

Finally, Finally, the probability of deconstruction was determined using a Gaussian function to predict the quantities of deconstructed materials produced each year [3]. The average lifespan of each building was assumed based on the lifespan of the materials composing the building's walls. Table 3 defines the average lifespans of each material based on the study by Mequignon [4].

Tableau 3 Average lifespan of materials used for walls [4].

Material	Lifespan (years)
Hollow concrete block	100
Terracotta	150
Massive stone wall	200
Traditional timber frame	100
Formwork concrete	100

Construction and demolition waste was estimated for the 2024–2030 period using deconstruction scenarios. In 2025, figure 3, waste generation is estimated at 254 kt, of which 41% originates from Nantes Métropole. Single-family houses account for 79% of the waste, and 65% comes from buildings constructed before 1945. Concrete represents more than 75% of the generated waste. These results make it possible to anticipate waste flows and to adapt resource management and recycling strategies accordingly.

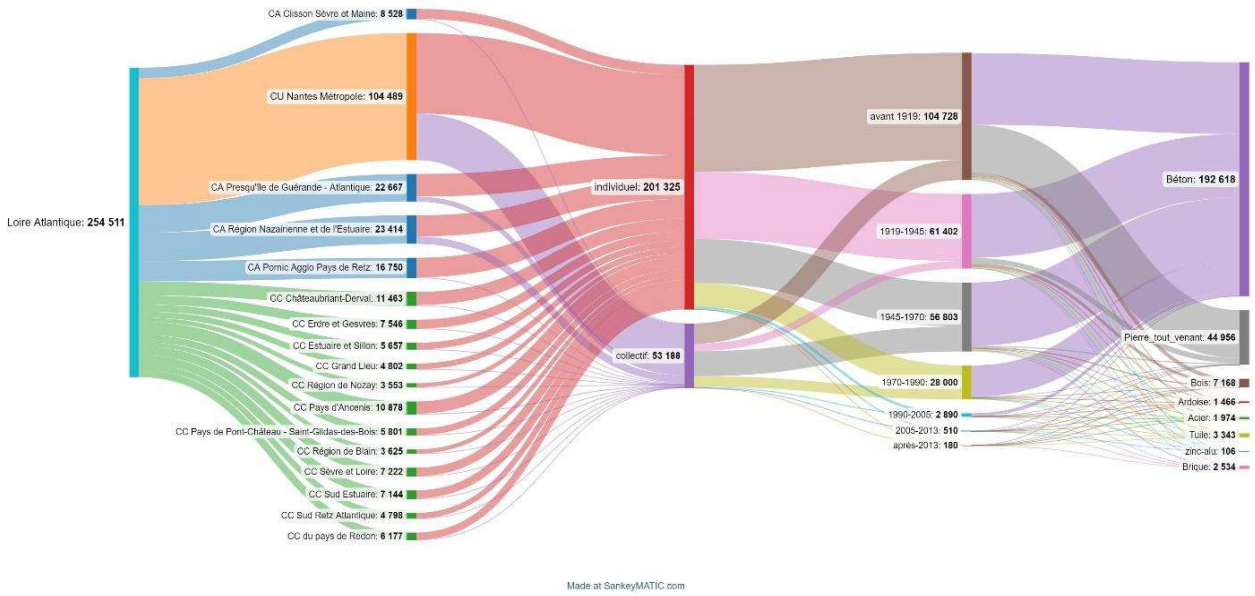

Figure 3 : Sankey diagram representing the waste flows produced in 2025 in the Loire-Atlantique department.

Reference

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[2] « Vers une atténuation de la dynamique démographique de la Loire-Atlantique - Insee Analyses Pays de la Loire - 119 ». Consulté le: 4 avril 2025. [En ligne]. Disponible sur: https://www.insee.fr/fr/statistiques/7703615#tableau-figure2_radio1

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[4] M.-A. Mequignon, « Comment la durée de vie des bâtiments peut-elle influencer les performances en termes de développement soutenable? », These de doctorat, Toulouse, INSA, 2011. Consulté le: 27 octobre 2023. [En ligne]. Disponible sur: https://www.theses.fr/2011ISAT0032