

Forecasting Model to Evaluate C&D Wastes by Maintenance and Refurbishment: The Case of Le Vallette

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Abstract: The urban regeneration lies on closed loops of energy, materials, information. The aim of case study is to evaluate and support policies of urban regeneration. The topic of the study is the control of waste flow made by the C&D (construction & demolition) activities involving the urban district. Each building produces a continuous flow of wastes during its predicted service life. This flow is mainly due to small building sites that generate small amount of wastes. In this way the collection, recycle and reuse material can be less accurate. In a regeneration perspective the reused and/or recycled part must be maximized. The study develops a GIS (geographic information system) based model for the assessment of the maintenance workloads of wastes produced. Coming from the data available by the public authorities and the survey on sites, the research group has carried out evaluation of the amount of wastes for building envelope, interior refurbishment of apartments, roads and parking lots. The output is a raw estimation of the C&D wastes by the maintenance and refurbishment of an urban district in Turin based on real evaluation of works needed.

Key words: Regeneration, maintenance, C&D wastes, building stock, urban metabolism.

1. Introduction

During the use phase of a building, it is necessary to put forward the disposal of construction products generated in the maintenance and refurbishment works. Such wastes, from small dismantling operations rather than from major works, contribute sensitively on total waste from C&D (construction & demolition). In Italy the C&D wastes are estimated to 48 million tons per year, i.e. 37.4% of total non-hazardous special waste [1]. According to the report *Recycle*, drafted by Legambiente, in Italy the production of C&D wastes is 0.8 tons per person, a lower result if compared with European average (1.09 tons per person). National and regional aggregate data do not allow to verify the real amount of C&D wastes.

In Europe, two legislative instruments manage and promote the proper disposal of waste including C&D: the European Directive 2008/98/EC and the European List of Waste 2000/532/EC. The former directive

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promotes the waste hierarchy through “a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal” [2].

The study presented is referred to a large stock of residential buildings for which a maintenance/end of life scenario is not generally anticipated at the design stage.

The building stock is mainly managed by ATC (Agenzia Territoriale per la Casa), about 40% of the total in neighborhood Le Vallette in Turin. The maintenance and refurbishment of such a building stock requires a number of building sites established every year in the city area. In addition most of the buildings in that area can be considered heritage, the construction going back to the 1960s. The financial significance of such activities is evident as well as the environmental consequences in terms of emissions, wastes and energy consumption. In this perspective, good management of such works is very important. On one hand a good quality of buildings means a good quality of life for inhabitants. On the other hand an

appropriate use and maintenance of the building stock affects the environment. In this way a good maintenance management by a big public housing agency can contribute to the urban regeneration. In other words durability of buildings and of its parts can affect in a substantial way the expenditures for maintenance as well as the environmental load in a substantial way.

2. Aim and Methodology

The aim of the research is to develop a user friendly method to forecast the amount of major maintenance works is needed and to assess the impact of such a work on the environment in terms of C&D wastes. In other words the goal of the research is the development of a tool to support decisions in maintenance and C&D waste management policies.

The method developed can help in an eco-efficient management of the waste generated in the use phase, e.g. the replacing of building elements, the refurbishment of an apartment etc.

This method is based on the following elements:

- a technological analysis of the building failures based on FMEA (failures modes and effects analysis) and on scientific literature focused on building pathology and defects;
- survey sheets to assess the degradation levels;
- building features data (height, surface, typology etc.) from GIS (geographic information system);
- algorithms to calculate the maintenance needed according to the results of the previous survey.

Interventions in terms of wastes produced are defined “a priori” in the FMEA (failure mode and effect analysis) carried out by the research group for each type of building. The priority for intervention as well as durability of the building parts can be considered as input of the model that can affect the output and scenarios. The study is based on a summary survey of buildings implemented by the research group.

This survey is aimed to detect degradation

phenomena and collect data on the condition of the buildings. Survey sheets provide raw information on defects and failures of the main parts of the building fabric and fixtures. The different types of building elements and technologies have been considered in the development of survey sheets by the research team. The GIS is used to collect the data of buildings and to geo-reference them. Main features and data, such as elevation, perimeter, façade surface and roof area, are calculated directly from the GIS model implemented in this study by the research group. In this way a raw estimate of works is feasible without a detailed survey and building mapping.

According to the knowledge available and literature on building degradation processes the research develops an evaluation scheme of the causes and consequences of any failure detected by the appraisal of phenomena in terms of maintenance needs and wastes from demolition. Moreover the priority of the interventions for safety and impacts on building performances has been taken into account. In other words, priority and maintenance intervention are coupled to the effects, extension and level of degradation identified by the building managers in the survey. The building part breakdown is aimed to the detection of degradation phenomena and of maintenance works to keep the building systems fully functional. In addition, the identification of parts is useful to collect data for the characterization of the behavior over time. Moreover the comparison between the age of the buildings and parts and the levels of degradation represented by the phenomena described in the sheets will allow predictions about the need of maintenance operations in the future.

There are various levels of degradation of the building parts, depending on the consequences for the system in terms of deviations from the desired quality levels, corresponding to different interventions necessary to keep the desired standard. These four levels, corresponding to the priority of intervention, are:

Level 1. Failures affecting safety of the people;

Level 2. Major loss in functionality of the building (i.e.: increase in energy consumptions, degradation of other building elements by water penetration etc.);

Level 3. Loss of function of the single building element;

Level 4. Appearance of the building.

The assessment of a specific degradation level corresponds to a scenario of intervention. In such a scenario the quality level will be defined complying according to the agency policy, also in relation to the financial constraints. Different scenarios imply a quantity of wastes.

The calculation algorithm is based, therefore, on the following steps:

- Selection of the phenomena that present levels of degradation greater than or equal to the threshold identified “a priori” on the basis of the consequences and desired performance levels;
- Setting of intervention scenarios based on the predefined thresholds, made possible by the forecasting model;
- Updating of forecasts as a result of successive surveys and/or performing maintenance work of replacing parts that reset the age of the component to the time 0.

This approach would allow to refine the feedback coming to considering the peculiar features of each building in relation to the degradation mechanisms and loss of performance.

Therefore there is a need to develop a user friendly but accurate tool. The ease can be achieved by limiting the number of degradation phenomena observed to the most significant ones for maintenance purposes. The accuracy can be accomplished linking the assessments of maintenance works to objectively verifiable phenomena in survey activities and management (e.g. cracks, etc.).

Furthermore, the method is based on the assumption that many of the degradation dynamics are correlated with the wearing and then with the age of the building elements. The instrument used for the purpose of

collection of the information on the in-service behavior of the building parts is represented by the FMEA methodologies. Such analysis allows identification of the causes and consequences of failures on the building component and on the system as a whole. This assessment is reflected on the one hand in the identification of the individual phenomena of degradation. On the other to the classification of the consequences on the system in terms of compliance with safety requirements, energy saving, functionality and appearance and maintenance works needed.

The assumptions of the methodology are:

- The subdivision of building’s components into functional element;
- The identification of the main technological features of the materials used (e.g. concrete-based plaster, wooden window frames etc.);
- The main failures occurring during the building and components service life;
- The consequences on the building functions in terms of seriousness and priority;
- The maintenance works consequent to the failures;
- The strategy of maintenance works proposed has been estimated according to practice;
- The amount of C&D wastes produced by the each work considered.

Starting from these assumptions, the degradation levels, maintenance works and C&D wastes can be forecasted. The model has been completely designed and an application has been developed using ArcGIS and Windows Access software.

3. Case Study

The goal of the case study is to evaluate the amount of C&D wastes that can be produced yearly by maintenance and refurbishment of residential building stock in a city district by the forecasting model described.

The research has been focused on the district Le Vallette in Turin, a residential area of about 680,000 square metres (Fig. 1). This neighborhood was built

after the Second World War as a public housing development to address the increase of housing need due to growth of the city. The buildings were built by several housing agencies and managed for decades by ATC. Nowadays building stock has been sold partially to the tenants. In this district the buildings were built following the same standards and technologies above all for envelope, structures and internal finishing. Moreover the building stock analyzed has been partially refurbished and maintained by ATC technical staff. The neighborhood is composed by 253 apartments buildings that can accommodate more than 8,000 people.

The forecasting of maintenance works has been focused on the main interventions relating to the building envelope (façades and roofing), the refurbishment of apartments (fittings, interior finishes, screed, floorings, internal partitions, etc.) and the replacement of external pavements (parking lots and roads).

Table 1 shows the most significant features of the residential buildings and external area of the

neighborhood in regard to elements considered in calculation. The rate of renovation of the apartments has been assumed by real data of ATC management systems, based on a sample of more than 31,000 apartments in Turin. Every year ATC refurbishes about 800 apartments. Such works are scheduled when the tenants of the apartments move. This amount of works is easily assessed considering the rules of the agency in regard to standards to be complied by law.

The evaluation of the repairs and replacement of the external masonry wall has been carried out taking into account only the more deteriorated façades. Nevertheless the failures detected in such elements do not require necessarily urgent interventions for safety reason (Priority 1). Such failure (the surface spalling of external brick wall) actually could actually have serious consequences on functionality of the wall and requiring a complete rebuilding of the wall. Therefore in the calculations we have assumed the need of replacement of the wall but only for the more widespread phenomena.

For the evaluation of roof maintenance we assume



Fig. 1 GIS model of Le Vallette, Turin.

Table 1 Case study—district Le Vallette, Turin. Residential building envelope data.

Envelope elements	Technology	Quantity [m ²]	%	Data source
Roof		144,867		GIS of Turin, average slope 27°
Opaque envelope (external surface)	Total	326,381		GIS of Turin
	Plaster	58,749	18%	Estimated from survey
	Brick wall	267,633	82%	Estimated from survey
Glazed envelope	Total	44,507		GIS of Turin
	Wood frame + single glass	8,901	20%	Estimated from survey
	PVC frame + single glass	15,577	35%	Estimated from survey
	Aluminum/steel + single	8,901	20%	Estimated from survey
	PVC frame + double glass	6,676	15%	Estimated from survey
	Aluminum/steel + d.g.	4,451	10%	Estimated from survey
Apartments: Total apartments/total apartments renovated per year			3,897/97	
Road and parking lot area: Total area asphalted [m ²]		283,970		

that the façade repair can be combined with the roof repairs in order to save money by using the same scaffolding. The roof tiles replacement is often required in these buildings that are more than 50 years old not refurbished yet.

4. Results

The outcomes of the estimate have been calculated on the basis of survey carried out by research team from May to July 2018 following the methodology described. The evaluation of C&D wastes by the refurbishment of apartments takes into account standard works by ATC agencies when the tenants move from the apartments. The amount of wastes (Table 2) due to maintenance and refurbishment in the case study of Le Vallette is approximately 3,000 tons per year, about 0.4 tons per person per year. In the last decade the pro capita production of C&D wastes in Italy is about 0.8 ton/year.

About half of the C&D wastes are from the refurbishment of apartments.

For only building envelope, the average quantity of C&D wastes produced in the sample of buildings investigated has been estimated in 0.13 tons per person per year, about 1,100 tons total per year.

A raw comparison with the literature about the amount of C&D wastes at the national level as well as the amount of refurbishment and maintenance on the construction sector output seems to comply the results

from the case study analysis.

As a conclusion of this phase of the research we can assume that the model and software developed show a significant amount of C&D wastes coming from refurbishment and maintenance works. Furthermore the georeferenced data allow us to identify the most critical buildings. The tool developed can also be useful to address technical survey to assess the reason of the degradation and failures more deeply. The outcomes of the survey based on the development of the forecasting model of building maintenance and refurbishment applied to a relatively small sample suggest a good fit of the model with the real behavior and durability of building elements. Nevertheless we have to remember that the amount for the quantity of C&D wastes could change following different maintenance strategy and standards. If we considered only the more critical failures requiring quick interventions and the apartments refurbishment, mainly related to the housing market trend, the amount of C&D wastes can be reduced from 0.4 to 0.2 tons per person per year. The amount of C&D wastes produced by the maintenance and refurbishment of building in a residential district is considerable. Also taking into account the most urgent interventions and the business as usual turnover of tenants the estimate is about 30% of total amount of C&D wastes in Italy. If we consider all works forecasted by the model, the percentage rises to about 50%.

Table 2 Case study—district Le Vallette, Turin. Amount of C&D wastes result.

Envelope maintenance works	Materials	Surface [m ²]	Volume [m ³]	Weight [tons]
Roof	Roof tiles	8,090	1,396	299
Opaque envelope (external surface)	Plaster	25,832	387	697
	Brick wall	1,353	162	93
Glazed envelope	Wood	45	2	2
	PVC	111	2	2,5
	Aluminum	67	1	2
	Glass	2,513	10	24
Apartments refurbishment	Materials	Surface [m ²]	Volume [m ³]	Weight [tons]
C&D wastes	Bricks	1,516	182	219
	Aggregate	25,125	503	906
	Metals	375	8	52
	Wood	1,525	61	73
	Ceramic tiles	6,850	137	205
Road and parking slot replace		Surface [m ²]	Volume [m ³]	Weight [tons]
Replace area per year (0.03 m thickness asphalt replace)		8,519	256	690
Total amount of C&D wastes		Surface [m ²]	Volume [m ³]	Weight [tons]
Plaster		25,832	387	697
Bricks		2,869	344	312
Metals		442	9	54
Glass		2,513	10	24
Wood		1,570	63	75
Aggregate		25,152	503	906
Roof tiles		8,090	1,396	299
Ceramic		6,850	137	205
Asphalt		8,519	256	690
Total			3,105	3,263

5. Conclusions

The large amount of C&D wastes shown by the research implies a more accurate separation of materials. For maintenance and refurbishment activities the relatively high cost of collection of C&D wastes, although very significant in quantity, requires innovative policies to improve reuse and recycling materials and building components.

The considerable amount of waste produced each year leads to the idea of setting up collection centers located in urban areas capable of treating waste materials before they reach landfill sites. The adoption of such a policy would improve the quality of collection allowing a better separation and recycling of materials. Nevertheless a revision of the policy could require innovation also in legislation.

On the basis of the results of the research we observe:

- The calculation method developed allows a quick assessment of maintenance workloads as well as C&D wastes;
- The use of the GIS and of existing database can help to assess the amount and geo localization of C&D wastes improving the management of recycled materials;
- Durability and technical features of materials and components affect the urban waste cycle and the urban regeneration and can be improved highlighting the importance of quality of materials.

The research and case study appear to have been answered and to be relevant also for investigation in other urban context and the methodology could be improved with the contribution of specific tools as BIM.

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