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Refurbishment of historic buildings at a district scale: *Enhancement of cultural value and emissions reduction potential*

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Abstract. The historic buildings have a significant value in providing a sense of identity to the cities and the community. On the other hand, due to their age, they show the highest ratio of living discomfort and energy consumption. Therefore, their refurbishment is a very important process because, if done right, it will not only reduce their energy demand and increase the living comfort but will also strengthen the social and cultural benefits through leisure and tourism.

In the city of Trondheim, as in many other European cities, the historic buildings have been erected in different architectural periods, which manifest diverse historic and technical features. A categorisation of the wall sections of historic buildings has been done for each city's development period regarding their construction material and technique, building functionality and protection status.

The scope of the article is to estimate the potential for reduction of greenhouse gas emissions at a street/neighbourhood/city level prior to applying large-scale intervention measures. This can be achieved by proposing refurbishment alternatives for wall and window sections that preserve the historic value and at the same time, approach or even meet the actual technical standards. Afterwards, the carbon footprint of the refurbishment action itself and the environmental benefits after the refurbishment (operational phase) is estimated for each category of wall sections. The environmental results, multiplied with the total surface of sections carrying the same attributes, give the overall potential of reduction for the entire group of buildings. Based on this, the on-site renewable energy that would lead to achieving zero-emission targets can be calculated. The framework is also important because it does not treat each building separately, but it suggests refurbishment scenarios for specific categories of buildings built in different historical periods.

1. Introduction

By definition, a historic building is a single manifestation of immovable tangible cultural heritage in the form of an existing building [1]. In addition, a historic building manifests significant cultural, artistic, and social values which gives a specific scope to its refurbishment process. For spreading the refurbishment of historic buildings at an urban scale (street, neighbourhood or city), the definition should encompass not only the very valuable historic buildings (the so-called monuments) but also a large number of buildings in European towns and cities which are far less important from a historical and architectural point of view but, taken as a whole, represent an important part of heritage [2]. By doing so, the intervention process at district scale will incorporate residential buildings or relatively recent buildings, which have protection status from governmental institutions.



However, due to the wide range of required expertise and the complexity of the interdisciplinary research, the overall intervention process in historic buildings is a complex issue that needs to be effectively resolved. Generally, the affected groups of stakeholders attempt to make decisions in their favour and sometimes the collaboration among different categories of stakeholders seems complicated for lack of an integrated framework and interconnected vision covering the different perspectives. Moreover, an extended literature review concluded that sustainable improvements are based on the operational phase i.e., after the conclusion of interventions and no method considers the environmental impact of the refurbishment process itself [3].

The European projects related to maintenance of historic buildings are primarily focused on energy efficiency solutions [4, 5], as suggested from the directive of the European Parliament [6]. Regarding environmental impact, a framework that considers the carbon emissions in the selection of interventions has been proposed for the maintenance of masonry building [7]. This paper discusses further the importance of the environmental approach in the decision-making process, in order to select the most suitable adaptation interventions which can be applied to diverse categories of buildings. Indeed, the built environment has different attributes depending on the location, materials, history, time of construction, esthetical features, etc. Systematic and clear categorisation of the built environment according to the construction techniques, architectural values, buildings maintenance and performance conditions might be a helpful step to insert the process of refurbishment in a standardized path that is understandable to each practitioner.

To achieve satisfactory results from plan to practice, it is required strong cooperation from specialists of different fields such as urban planners, architects, engineers, researchers, building conservators, buildings owners and others involved in heritage management [8]. This article aims to group the main attributes, meaningful for historic buildings, into three main categories: technical, heritage significance and environmental impact related. The combination of the scale of material decay and its historic value would lead to the suggestion of appropriate refurbishment works that retain significance while the environmental impact of the work during and after refurbishment would be the driver for selection of sustainable scenarios.

2. Materials and methods

As the name “sustainable refurbishment of historic buildings” indicates, the involved groups of interest can be grouped in three main categories: the materials’ science community (service life and risk assessment specialists), cultural heritage specialists (historians, architects, governmental institutions) and the sustainability community (with a special focus on environmental impact). Each of the main communities evaluates the built environment in specific aspects and the results are commonly expressed in grading systems regarding respectively the level of decay, historic value classification and amount of environmental impact.

2.1. Decay assessment

Buildings are prone to changing requirements over long periods and it is very important to work with the time rather than against it. For this reason, service life prediction (SLP) is an important process prior to interventions that should be applied to existing buildings [9]. There are many ways for calculating the SLP but according to the report “Performance-based methods for service life prediction” [10], the methods have been divided into two major groups: factor methods and engineering design methods. The application of the methods estimates the service life for a particular component or assembly (in years) by considering specific technical conditions. According to the factor method, the service life (in years) is calculated on the basis of the following equation:

$$ESL = RSL \cdot f_A \cdot f_B \cdot f_C \cdot f_D \cdot f_E \cdot f_F \cdot f_G \quad (1)$$

where ESL = estimated service life; RSL = reference service life; f_A = factor A: quality of components; f_B = factor B: design level; f_C = factor C: work execution level; f_D = factor D: indoor environment; f_E = factor E: outdoor environment; f_F = factor F: in-use conditions; and f_G = factor G: maintenance level.

The service life prediction is strictly connected with the decay assessment process because the indoor and outdoor environment can create a proper state for decay. The level of decay (in %) is linked with the value of the SLP (in years) through polynomial functions as shown graphically in Figure 1.

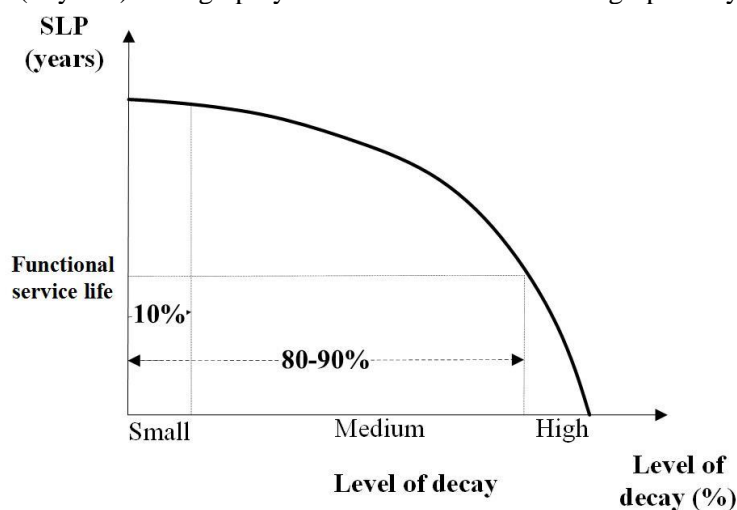


Figure 1. The link between the service life prediction (SLP) and the level of decay of the materials.

The prediction of the decay rate on building components is a necessary step to determine the time when a refurbishment process should be conducted before the end of technical/functional service life is reached i.e., before the component is rendered obsolete. The categorisation of decay results during the decay assessment (small, medium and high) would serve as the starting point in suggesting refurbishment interventions and their frequency of application.

For building components which are estimated to live for decades, the value of SLP needs to be corrected by introducing a new correction factor that considers the effects of the climate change in construction materials. Moreover, when the interventions are applied to historic buildings which hold in addition cultural and social values; the location, aspects of use, and the economic cost should be assessed in the final calculation.

2.2. Historic value assessment

Although a historic building does not necessarily have to be a heritage-designated building, its expected standard lifespan is considered at least twice longer than the lifespans of a building with no or low significance value. For this reason, they require high-quality interventions to ensure long term performance of the building, secure convey of their values and fulfilment of sustainability-driven criteria.

Based on the value that they represent, historic buildings have different protection statuses which can be of an international, national or local level. The international or national institutions (UNESCO, ICOMOS, Riksantikvaren in Norway, etc.) deal mainly with the conservation of the outstanding buildings (the so-called monuments) which have specific protection status and big restriction for change. The protection status of this group of buildings is regulated mainly from municipalities following the restrictions and requirements during the intervention processes.

In the city of Trondheim, apart from the listed buildings (Fredet), there is a large number of protected buildings (Vernet) which are categorised in three main groups (A, B and C) according to the value that they represent [11]. Further interdisciplinary developments (e.g. DIVE method [12]) have been applied in some case studies to these historic buildings in order to categorise them according to the value and giving instructions about the type of the intervention for building component [13]. The recommendations and limitations of the groups of historians, architects and others involved in cultural heritage preservation need to be included in the suggestion of the refurbishment scenarios that need to be applied in protected buildings.

2.3. Environmental assessment

The interventions in historic buildings need to follow the sustainability principles and to adopt the minimal technical interventions through principles of compatibility, reversibility and retreat-ability. The environmental impact of the intervention works can be assessed by applying the Life Cycle Assessment (LCA) analysis [14, 15] to the materials and processes used during the adaptation procedure. According to the EN 15978:2011 standard [16], the intervention works refer to the modules B2 until B5, respectively Maintenance (B2), Repair (B3), Replacement (B4), and Refurbishment (B5).

3. Results

The historic and cultural assessment of buildings indicates the issues to deal with regarding their protection class, rather than dealing with exact instructions on how these problems should be solved [12]. On the other hand, prediction of the materials durability for different building components tells when and where the refurbishment intervention should be done, but not what type of intervention is needed. For this reason, the results of these two independent assessments should be merged prior to deciding the type, the time and the location of the intervention. Both the results of the decay and historic assessments are obtained from classifications which are independent of each other and can be shown in a 2-D chart (Figure 2).

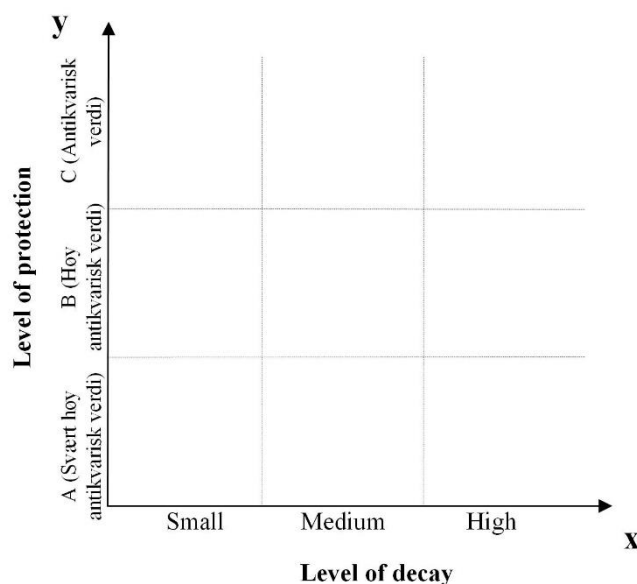


Figure 2. Regrouping of building components according to their decay status and protection level.

The service life is predicted for building components or assemblies' level while the categorisation according to the historic value is performed at building scale with different suggestions about interventions that are allowed to different components.

Each of the cells in Figure 2 contains information about the durability and performance of the constituting component/assembly (level of decay – x-axis) and the scale of allowed intervention in accordance to their protection status (y-axis). For each cell, a refurbishment intervention technique that fulfils both the requests of reducing the decay and keeping unchanged or enhancing the value is provided.

In most of the cases, especially in components with high capacity to change, different scenarios of interventions achieve this dual goal. Therefore, the most appropriate intervention scenario is selected in accordance with its environmental impact. Given the fact that the proposed refurbishment scenarios approach or even meet the actual technical standards [17] (e.g. thermal insulation), then the environmental impact of how it is achieved should be considered. Moreover, applying the environmental

impact of the refurbishment works as a driver for scenario selection, would lead to the principles of maintenance, repair and reuse as much as possible from the original fabric over the replacing procedures, which is in the same line with the standard approach used by conservators. The new variable transforms the diagram of Figure 2 from a 2-D chart into a 3-D chart (Figure 3) with embodied emissions of the intervention works (modules B2-B5 regarding EN 15978:2011) as the third constituent of it.

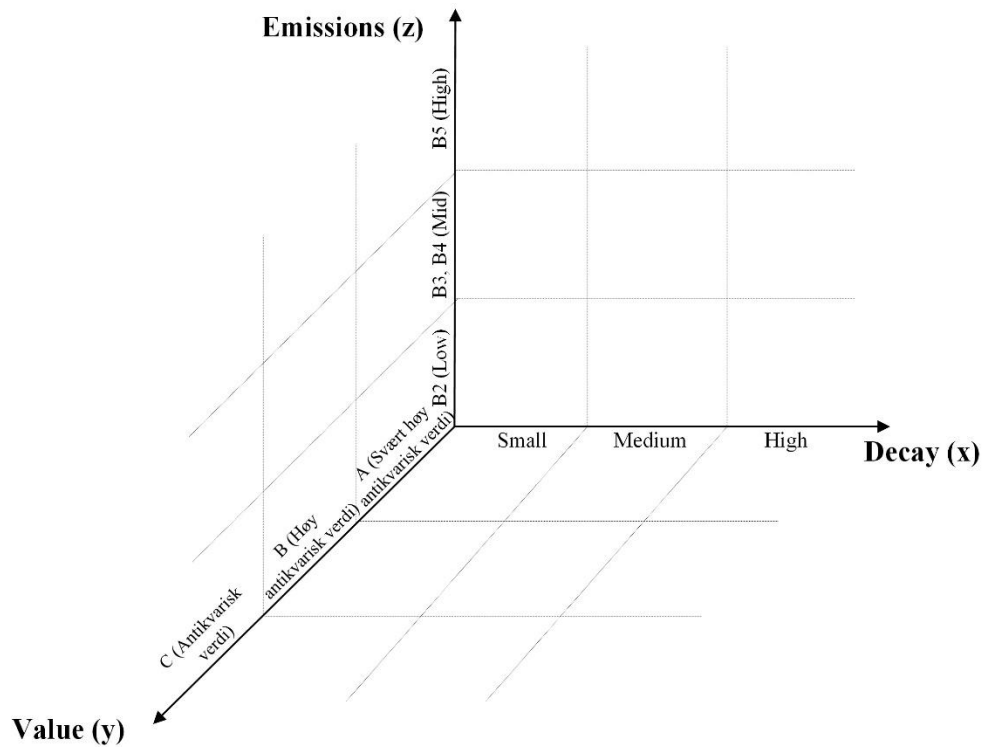


Figure 3. Inclusion of the environmental cost (embodied emissions) of the intervention works in the decision-making process.

However, in common practice, especially in public procurement works, the variable that mostly drives the decision of following a specific scenario rather than others, is the economic value of the work. In the new diagram, the monetary aspect is partially considered looking at the prediction of the level of decay and therefore the SLP (x-axis) and together with the law restrictions established to retain building historic, cultural and social values (y-axis) and the environmental impact in the z-axis, they compound the three pillars of the sustainability (environmental, social and economic) in the decision-making process.

Ideally, a good refurbishment would not only keep the same level of decay and protection class but would help to decrease the decay category and enhance the historical value of the building. Therefore, the next refurbishment rounds and the building itself would result in less environmental cost because the demand for the next interventions would be of a smaller scale and with an increased time of intervention intervals.

As our goal is the sustainable refurbishment of historic buildings, the main focus will be given to the components connected directly to the energy efficiency and GHG emissions, i.e. the external components such as outer walls, windows and roof. The environmental impact should be firstly estimated for the intervention processes itself (modules B2-B5 regarding EN 15978:2011) and later, the emissions during the operational phase B6 should be calculated in order to evaluate the payback energy to be generated by renewables. The emissions for each intervention scenario suggested for each cell of Figure 3 (for each component with a certain level of decay and historic value class), are calculated at the unit level which can be for 1m^2 for walls and roofs or unit for windows.

The aim of the framework is to estimate the potential of the reduction of the emissions of buildings with similar typology and technique of constructions in the street, neighbourhood or city scale. Depending on the typology of constructions, this can be achieved in two ways:

- When the buildings are very similar to each other (e.g. surface and number of stories), the results of emissions from the refurbishment of an unit scale (1m^2) can be multiplied with surface of walls of a building to estimate the results at building scale and then multiplied per number of similar buildings to achieve the carbon footprint of the specific work at district scale. A sum of the emissions of each “winning” refurbishment work corresponding to each cell of Figure 2, would give the total impact of the entire refurbishment of the district.
- When the neighbourhood is heterogeneous regarding surface and height of buildings, the emissions’ results from the refurbishment in unit scale can be multiplied directly with the surface of walls at district scale with similar shared criteria (the same value in x and y-axis) to estimate the environmental cost of the similar work and then, of the whole neighbourhood.

3.1. Example of application

The method described above has been applied to two buildings with different status of decay and level of protection. The application of the framework in an entire district is an ongoing process that will be published on a later stage of the study.

The buildings are located in Møllenberg area in Trondheim as it is shown in Figure 4. Because of the esthetical attributes that they carry, the municipality of Trondheim has classified Building 1 with the level of protection C and Building 2 with the level of protection B.



Figure 4. Photos of the Building 1 (left) and Building 2 (right) situated in Wessels Gate in Trondheim.

The service life prediction has been estimated for both wall sections using the factor method. The lifespan of the wood products in construction is over 30 years, but for some components, it reaches more than 100 years [18]. For typical timber log wall, the reference service life (RSL) has been assumed 50 years. Factor values for each component of the equation (1) have been selected according to the recommendations of ISO standards [19, 20] as given in Table 1.

Table 1. The factor values for the estimation of the service life.

Factor	Building 1		Building 2	
	Condition	Factor	Condition	Factor
A – Inherent performance level	Good quality	1.2	Good quality	1.2
B – Design level	Normal design	1.0	Good design	1.2
C – Work execution level	Normal	1.0	Normal	1.0
D – Indoor environment	Average risk	0.9	Average risk	0.9
E – Outdoor environment	Frequent risk	0.8	Frequent risk	0.8
F – Usage conditions	Residential use	1.0	Residential use	1.0
G – Maintenance level	Reduced maintenance	0.8	Good maintenance	1.2

The estimated service life ESL of the walls of the building 1 and 2 are:

$$ESL_1 = 50 \times 1.2 \times 1.0 \times 1.0 \times 0.9 \times 0.8 \times 1.0 \times 0.8 = 34.56 \text{ years} \quad (2)$$

$$ESL_2 = 50 \times 1.2 \times 1.2 \times 1.0 \times 0.9 \times 0.8 \times 1.0 \times 1.2 = 62.21 \text{ years} \quad (3)$$

The ESL of the external wall of Building 1 is approximately 70% of the RSL which corresponds to medium level of decay. In Building 2, the ESL is higher than the RSL due to good cyclic maintenance which makes the level of decay of a small scale.

The buildings have been constructed at the same time and their typical log sections (Figure 5) are similar for both buildings. Both the wall sections, after additional insulations works performed in the '80s, have a thermal value $U = 0.32 \text{ W}/(\text{m}^2\text{K})$ while according to the actual Norwegian TEK17 standard, this value for outer walls should be below $0.18 \text{ W}/(\text{m}^2\text{K})$ [17]. Walls have vapour barrier layers on both sides, recommended for cold climate, to avoid the risk of condensation. However, due to different levels of protection and levels of decay, different intervention scenarios will be suggested to them in order to reduce the decay and improve thermal performance.

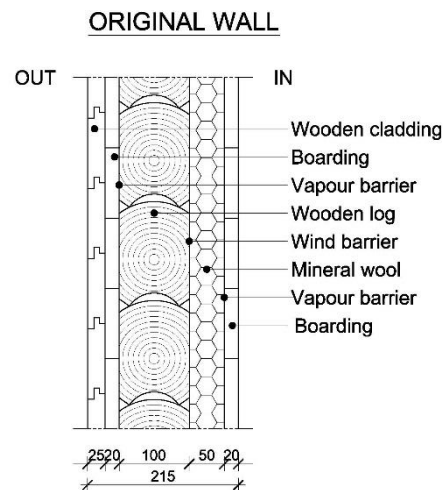


Figure 5. The original section of the wall sections

In Building 1, with C level of protection, it is allowable to have intervention works from outside. This type of intervention is also recommended as the thermal insulation is spread uniformly through the wall, minimizing cold bridges. To reach the desired U-value and reduce the decay, it is recommended to add 50 mm of insulation from outside and replace the original external cladding. This is the only scenario suggested for this type of wall (Figure 6). Another scenario would be the implementation of insulation works from inside, but this option is excluded because, as the external cladding needs to be replaced, it gives the possibility to work from the outer side.

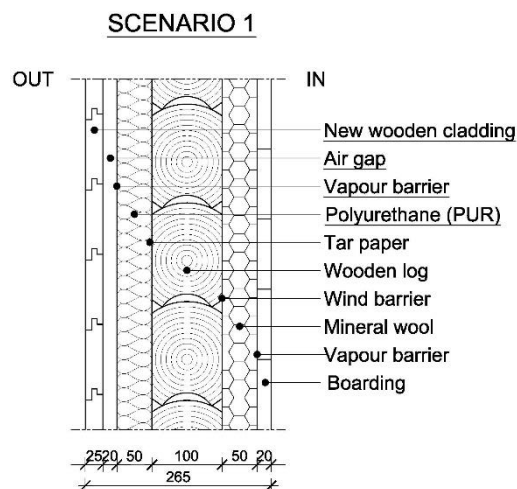


Figure 6. The proposed scenario for the outer walls of Building 1.

New paint of the façade is also included in the intervention works. The carbon footprint is calculated for middle change (Repair, Replacement) and it consists of the emissions for the production and transportation of new materials, the emissions during the installation works and the emissions of the end of live processes for the old materials:

$$E = E_{(p)} + E_{(t)} + E_{(i)} + E_{(eol)} = 19.17 + 0.64 + 0.23 + 2.45 = 22.49 \text{ kgCO}_{2eq} / \text{m}^2 \quad (4)$$

For building 2, the intervention works will be executed from inside due to the protection status of the building. The wall is in generally in good conditions, but its thermal insulation needs to be improved. For this, two intervention scenarios are suggested: additional insulation from inside or replacement of the original insulation as shown in Figure 7.

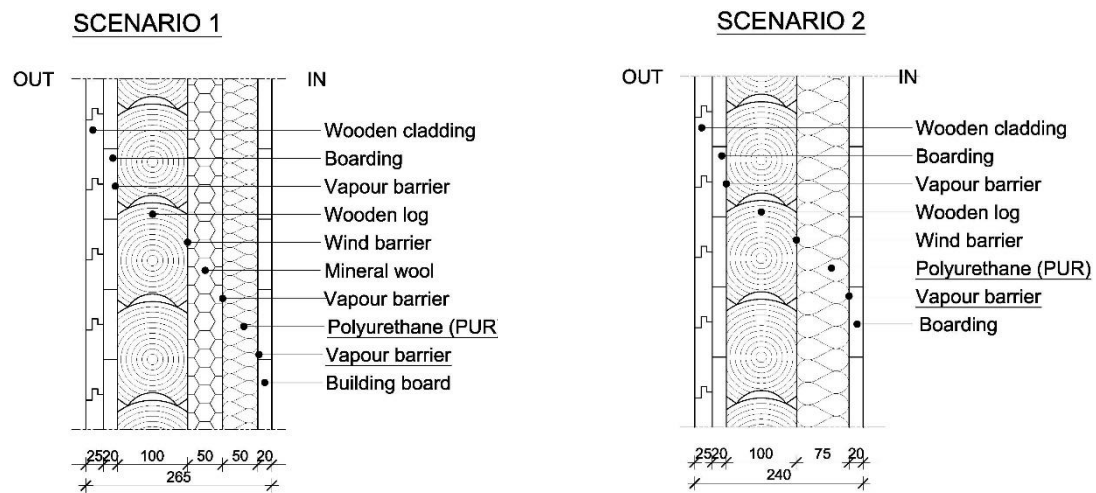


Figure 7. The proposed scenarios for the outer walls of Building 2.

Both scenarios reach the recommended U-value, therefore it will be the carbon footprint of the works which will be the driver for the selection. The environmental cost of the scenarios is calculated still for middle changes as follow:

$$E_1 = [E_{(p)} + E_{(t)} + E_{(i)} + E_{(eol)}]_1 = 5.70 + 0.14 + 0.08 = 5.92 \text{ kgCO}_{2eq} / \text{m}^2 \quad (5)$$

$$E_2 = [E_{(p)} + E_{(t)} + E_{(i)} + E_{(eol)}]_2 = 8.65 + 0.14 + 0.12 + 3.55 = 12.46 \text{ kgCO}_{2eq} / \text{m}^2 \quad (6)$$

From the comparison, the first scenario is the most environmentally friendly.

The 3-D chart that connects the level of decay, level of protection and level of embodied emissions of the interventions is given in Figure 8 for both buildings. The carbon footprint of the repair/replacement interventions for 1m^2 , multiplied with the total area of walls with similar features in the entire neighbourhood, generates the environmental cost of each work at the district level. The same procedure can be applied to different combinations in the 3-D chart, which encompasses all possible cases that can be met in the district.

The intervention works aim simultaneously the reduction of the level of decay, minimisation of the carbon footprint of the actual/ future interventions and whenever it is possible, the increase of the protection class of the building. Graphically speaking, the objective of the intervention works is to shift the entire set of dots in the 3-D chart as close as possible to the origin of the coordinates.

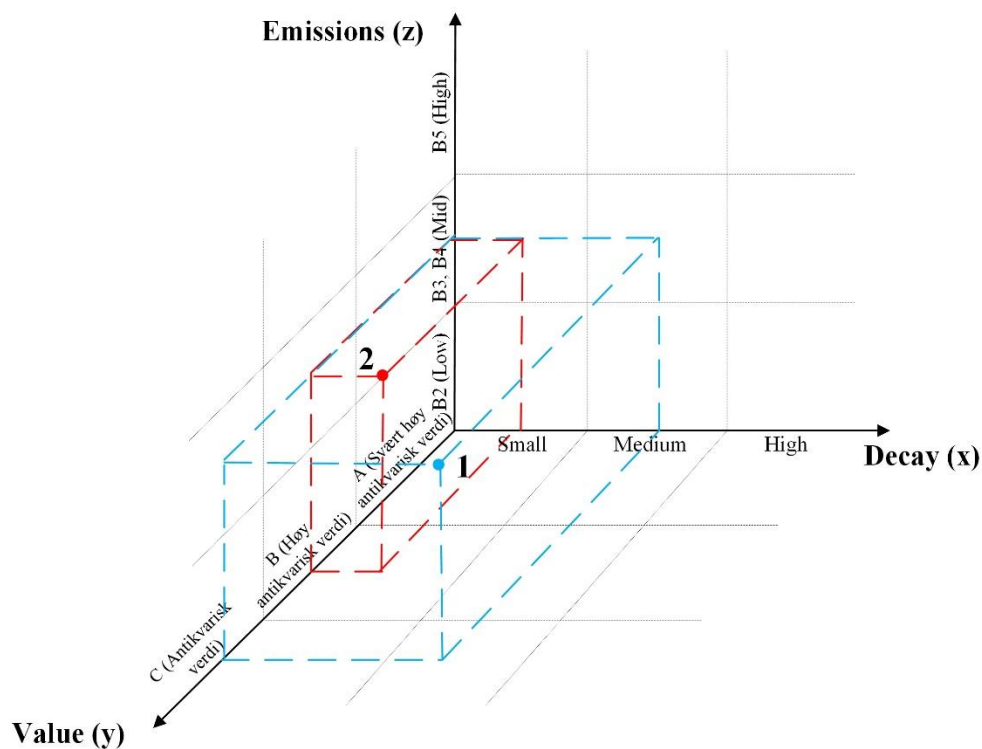


Figure 8. Position of the interventions in buildings in the 3-D chart (cyan dashed line for Building 1 and red dashed line for Building 2).

4. Discussions and Conclusions

The historic value of the building is the only non-renewable asset among the other assets and it should be preserved at any cost during the decision-making process. For this reason, it should be the primary driving factor during refurbishment works. Exceptions to this judgement can be done if the stability of the structure is compromised (due to hazardous events or long abandonment) and the proposed measurements may exceed the allowed level of intervention. After the historic and cultural values are ensured, their link with the level of decay of the material would suggest suitable refurbishment interventions. Considering the growing demands for minimizing the environmental impact, an intervention with satisfactory emission results during and after refurbishment can be preferred. By applying this framework, the results of each community remain independent and the conclusions of each component are taken into account.

The target of preserving the cultural heritage faces challenges in privately owned buildings, especially when the protection class is low. The proposed method does not treat the buildings individually, but it gives suggestions on a neighbourhood scale, thus enabling higher financing opportunities for private owners through collaboration with governmental institutions and involvement in larger projects.

The 3-D diagram presented in Figure 3 suggests a method to analyse, at once, the existing constraints and guidelines when planning an intervention to historical buildings, e.g. for improving the energy performance [21]. The technical compatibility, economic viability, use of the building and the indoor/outdoor environments are considered during the assessment of the level of decay strictly linked to the SLP; the heritage significance is ensured from the historic value assessment and law regulations; while the energy performance is the driver considered during the environmental assessment in a life-cycle approach.

The enlargement of the historic buildings' concept to a street, district or urban level reflects the refurbishment needs for specific categories of buildings, usually private residential houses, which were neglected in the previous interventions as they were not holding memorable historic values. The proposed method makes the path for sorting and assessing the limitations and possibilities of these

buildings regarding their historic values, physical characteristics or decay rate, easier and more flexible. Moreover, the assessment and then, the choice of a sustainable solution for groups of buildings that hold the same significance, preservation status and condition of the decay, would result in time and money-saving rather than treating each building separately. These results, incorporated with the energy efficiency reduction due to refurbishment works, help to estimate the operational energy needed from the neighbourhood which serves as a base for the calculation of energy produced from the renewables, thus facilitating the move towards Zero Emission Neighbourhoods in historic urban areas.

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