Escola de Camins
Escola Tècnica Superior d'Enginyeria de Camins, Canals i Ports
UPC BARCELONATECH

MASTER'S THESIS

Sustainability assessment of Brownfield Sites Redevelopment

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Master in:

Environmental Engineering

Barcelona, 23 of June, 2022

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Acknowledgments

First of all, I would like to thank my tutors Albert and Irene who accepted to support me on this subject when I came to them with this particular idea of working on brownfield sites and who helped me a lot to orient the objectives and method of this work. They allowed me to work in a independent way but have always responded to me really quickly when I needed their held or feedbacks.

I would also like to thank Marie-Hélène Marliangeas, which culture of the urban history and heritage of Marseille and knowledge of its port industrial zone have enriched a lot my reflexion and work. She has introduced me to a large ecosystem of actors working on this thematic in the city that have also nourish my reflection about my future professional.

To conclude, I would like to thanks the experts who participated to the survey I proposed them to make the results of this work the most reliable possible.

Abstract

In a context of rapid growth of the global population it is becoming essential to think about how to use the space in an efficient way. Indeed, it is no longer possible to let the cities eat progressively agricultural lands vital to feed this increasing population. And while the cities extend, we observe in urban areas number of old industrial sites, brownfields, left abandoned by the delocalization of productive activities out of the cities.

The objective of the present study is to evaluate the sustainability of brownfields rehabilitation projects. The idea is to compare the economic, environmental and social impact of the demolition of the old structure to install a new activity with the valorisation of the industrial building to propose new uses. The study aims at showing the benefits of an emerging vision of urbanisms, sparing resources and developing a circular urbanism.

To achieve this objective, a comparison model was build following the MIVES method, to support decision-making by public institutions that attribute subsidies to rehabilitation projects. The model was used and tested in a real case study to evaluate different projects of rehabilitation of an old industrial slaughterhouse abandoned in the city of Marseille in France.

The results show that, whatever economic or environmental arguments are considered more important, projects of reutilisation of the old industrial building are the most sustainable alternatives. Since they limit the energy and resources consumption and waste production during the construction period, they also reduce a lot construction costs. The future projects that the site can welcome are of course limited by the size of the existing structure, but the affordable price of these abandoned sites also allows the installation of innovative projects, with cultural and social purposes.

Resumen

En un contexto de aumento rápido de la población global se vuelve esencial pensar como utilizar el espacio de manera eficaz. En efecto, no es posible dejar las ciudades comer poco a poco tierras agrícolas indispensables para alimentar esta población creciente. Y aunque se extienden las ciudades se observan dentro de las ciudades antiguos edificios industriales dejados abandonados por el desplazamiento de la actividad productora fuera de las ciudades.

El objetivo del estudio es de evaluar la sostenibilidad de proyectos de rehabilitación de antiguas industrias abandonadas. La idea es de comparar el impacto económico, ambiental y social de demolición de la estructura vieja para instalar una nueva actividad con la valorización del edificio industrial para proponer nuevos usos. El estudio quiere demostrar los beneficios que representa una emergente visión del urbanismo, ahorradora de recursos, y que valora un urbanismo circular.

Para alcanzar este objetivo, se construyó un modelo comparativo a partir del método MIVES, para soportar la toma de decisión de instituciones publicas que atribuyen subvenciones para proyectos de rehabilitación. Además, el modelo fue utilizado y probado en un caso real de estudio para evaluar varios proyectos de reutilización de un viejo matadero industrial abandonado en la ciudad de Marseille en Francia.

Los resultados muestran que, cualquier sea el argumento con mas peso para la ciudad entre el económico o ambiental, los proyectos de reutilización de la estructura de origen son mas sostenibles. Porque limitan el consume de energía y recursos y la producción de residuos durante la fase de construcción, lo que también reduce bastante los costes de construcción. Los futuros proyectos que el sitio puede acoger son evidentemente limitados por el tamaño de la estructura existente, pero el precio bajo de estos sitios abandonados también permite la instalación de proyectos innovadores, con cultural y social proposiciones.

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1. INTRODUCTION

1.1. Definition

Brownfield lands are defined by the Environment and Climate Change Canada as "abandoned, idle or underutilized commercial or industrial properties where past actions have caused environmental contamination, but which still have potential for redevelopment or other economic opportunities" (Government of Canada, 2016).

The number of this sites in urban areas has significantly increased in Europe since the 1990's, because of the many industrial sites closures. This is mainly due to the delocalization of the production activity in developing countries or just the relocation out of the cities because of the high price of urban property and an increasing demand of the consumers. Therefore, the work organisation mutation results in urban mutations that we must consider.

1.2. Why redeveloping brownfields?

The main reason for working on brownfield redevelopment is environmental since the reuse of brownfields could participate to the effort to reduce urban sprawl. Soils artificialization has become one of the deepest challenges we have to face nowadays. In fact, the massive growth of the global population leads to a higher housing demand, but also a higher food demand, what can not match. Therefore, we must reduce urban sprawl that is an ecologic nonsense as much for its land take and soil sealing consequences than for the increase of home-work distances, that often leads to the use of individual cars.

We continue to build new housings and new buildings on green spaces, and potentially agricultural lands, whereas brownfield lands keep unused in the cities. Actually, it was estimated in 2014 that there were about 4.2 million brownfields sites in the European Union, of which 340.000 are expected to be contaminated (Van Liedekerke et al, 2014). In general, the high cost of decontamination of old industrial building is the main barrier for stakeholders and still limits a lot the development of rehabilitation projects on brownfield. The European Environmental Agency identified contaminated sites among which only 15% have been remediated, so there is still a large potential for improvement in this area (European Environmental Agency, 2021).

Not only brownfields redevelopment projects offer solution to land take issues but they also avoid the construction of new buildings and its impact on the environment. In fact, the buildings construction sector represented in 2019 about 5% of the global final energy consumption, and 10% of the global CO_2 emissions, an impact mostly due to the manufacturing of material such as steel, cement and glass (UN Environment Program, 2020). In addition, the rehabilitation of industrial sites, using the old structure, gives us the opportunity to limit the waste generation of the demolition process and the use of primary resources. Therefore, brownfields redevelopment projects form part of what we call circular urbanism, inspired by the concept of circular economy.

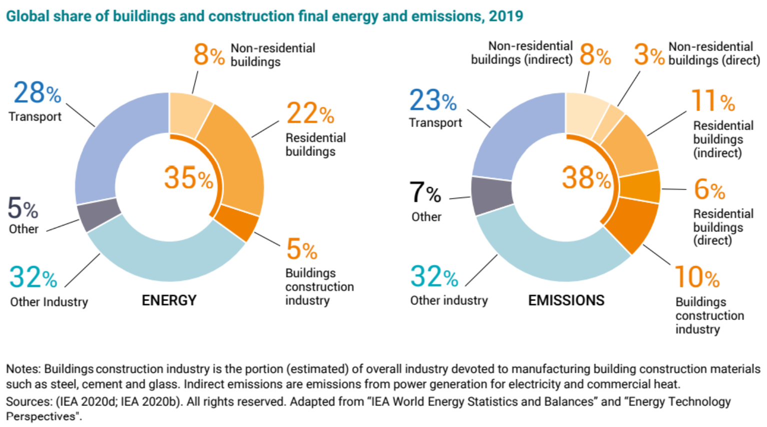


Fig.2: Source2020 Global Status Report for Buildings and Construction (UNO) (UN Env. Program, 2020)

The environmental benefits have been largely proven by studies and success stories all over Europe and have convinced the public institutions to dedicate public funds to these projects. The European Environmental Agency estimated that in 2014 an average of 42% of the total expenditure on the management of contaminated sites came from public budgets (EEA, 2021). In the last years, France has done great efforts to manage brownfields redevelopment projects: first with its « Zero Net Artificialization » objective written in the Biodiversity Plan of 2018 and then in its Economic Recovery Plan to overcome the Covid 19 crisis by investing 650 million euros for 2021-2022 to "finance brownfields recycling operations".

1.3. For what uses?

If we consider the definition we gave of brownfield sites, we must deal with an important diversity of sites: from contaminated green places to constructed areas, with diverse superficies, different sizes of buildings, from no contamination to high-level contamination areas. Therefore, the projects of redevelopment are also very different and can be classified in three groups:

- *Demolition to renovation*. The old building is destroyed to build a new structure on the same land, after decontamination works.
- *Brownfield sites turned green*. The site is decontaminated through remediation works and kept as a green space. These projects are very interesting to reintroduce nature in the cities, and for all the advantages, it brings such as the increase of air quality, the mitigation of urban heat island effect. However, for now, the high cost of remediation works limits this transformation.
- *Change of use*. This solution demands less money but also presents good environmental advantages. The buildings remain on the site and some construction works are done with the purpose of proposing a new use.

Fig.2: At the top: Old military barracks (left) become Darwin ecosystem (right), a third place in Bordeaux. At the bottom: Old train station (left) Station F, a clustering of offices for start-ups in Paris

The new uses given to the industrial building in the existing projects are very different too: use for a new industry, public services, new housings, cultural places (exhibitions, performances, artistic residencies), economic centers (business incubators, coworking, fablab…), social action (housing for people in need, immigrants), etc... These large areas generally welcome different projects and have multiple uses. This is the particularity of the so-called "third-places", which provide different services to welcome a large population of people and allows social diversity.

It is common in France that brownfields welcome third place projects, and success stories have multiplied in recent years. These projects will particularly draw our attention in the present work because of their interesting social impact. In fact, they contribute to bring new life and economical activity in some areas left abandoned. They can also provide new public services such as library, nursery for the neighbourhood and build the 15-minutes city model. Moreover, they often welcome various associations, allowing them to meet and enrich each other. Finally, the third places aim to be places of diversity, of meeting and exchange.

The new uses offered by the building rehabilitation can be temporary, while waiting for a new rehabilitation, or long-term projects. However, it has often occurred that temporary occupations had proven their sustainability and positive social impact and then continue their activity. Can Batlló in Barcelona is a great example of a social struggle becoming a sustainable project and an attractive place.

Fig.3: Can Battlo, barrio de la Bordeta de Barcelona

Therefore, in the last years, brownfield redevelopment projects have proven their benefits for cities but the present study propose to introduce a technical analysis of this projects and quantify their impact and sustainability. This work proposes to build a model to evaluate rehabilitation projects and to apply it to a case study in the city of Marseille, France.

2. METHODOLOGY

Many publications were carried out about the large subject of brownfield redevelopment, and introducing various thematic such as juridic, social, political, scientific, etc. Number of them propose an environmental study, mostly focused on the pollution mitigation of these sites. In fact, remediation, and especially bioremediation, methods are have developed a lot recently. Nevertheless, the environmental advantages of brownfield recycling projects are so much important in terms of circular system, economy of resources. In fact, besides their positive effects on biodiversity and human health, this projects also contribute to the limitation of greenhouse emission, contribution to global warming and resource depletion.

The objective of this study is to compare the classical model of deconstruction and reconstruction of the cities and the urban recycling projects, in order to know the most sustainable alternative for the growing number of abandoned sites. This scientific comparison method had to be quantitative, and we consider that not only environmental arguments are essentials but also economic and social ones. Therefore, we decided to use the MIVES method that we will explain in details then.

2.1. MIVES method

The Integrated Value Model for the Evaluation of sustainability, known by its Spanish acronym, MIVES (Modulo Integrado de Valor para una Evaluación Sostenible), is one of the various multi-criteria decision-making processes. It uses qualitative indicators to assess the sustainability of projects, products, in order to compare different alternatives and support decision making. For this work, MIVES method has been chosen for two principal reasons. First, it allows using both qualitative and quantitative indicators with different units and scales. Secondly, because its visual tree structure can be easily understood by non-experts and used as a political influence tool.

The method is based on the building of a decision-making tree organized in three levels: requirements, criteria and indicators. The study focuses on economic, environmental, and social impact, that are defined as the three main requirements. The final objective of the method is to attribute a grade value between 0 and 1 to the different alternatives, in order to be compared with one another. The evaluation is conducted following different steps (Pons et al, 2021) (Josa et al, 2021):

- Delimitation of the system boundaries.

- Construction of the decision-making tree by defining requirements, criteria and indicators scope.
- Attribution of value functions for each indicator. They are mathematical functions that give an approximated evolution of the satisfaction depending on the indicator values. From this model, we obtain a value between 0 and 1 for each alternative.
- Weight attribution for the tree elements at the three levels, depending on the importance of the element to evaluate sustainability for stakeholders.

All those elements are introduced in a program that calculates the normalised value (between 0 and 1) for each alternative's index. Finally, the results are analysed to identify the best alternative in terms of sustainability.

2.2. System boundaries

This study aims to assess the sustainability of brownfield redevelopment projects. It includes both rehabilitation project, whose particularity is to keep the old building and propose new uses, and demolition to renovation projects, the most common process.

The life cycle analysis (LCA) stages considered were (1) demolition of the actual building (2) site depollution (3) extraction and processing of the construction materials for the new building (4) new material and production (5) construction process (6) service life. The end of life and demolition processes were not studied because it depends on the adaptability of the building and the opportunity to welcome a new function, what would have complicated the work.

The present study was carried from the point of view of public institutions and local authorities. This work aims at proposing a support for decision-making for institutions because they play a significant role in the achievement of brownfield redevelopment projects in France. In fact, they are the ones that can give important subvention and have to chose the projects with more potential and benefits for the urban environment.

3. STUDY CASE

3.1.Brownfield environment

We have chosen to illustrate the method with a study. First, to integrate it in a reality and to test the model. And also because of the feature of our object of study, brownfields, that are very diversified, particularly in size, and therefore we can't define constant parameters for the value functions and they have to be determined for each study case. However, we will describe how those parameters have been defined in our case, and the method will always be applicable to other projects by being aware of adapting it to the considered building.

The city chosen for the study is Marseille, the second biggest city of the country with about 880 000 inhabitants, located in the south-east of France. It is a port city, and consequently has always been very industrial, mostly in the north or the city next to the maritime port as shown on **Fig. 4**. A few decades ago, the territory welcomed important traditional industries, such as soap factories really typical of the region, but lot of them are closed now. The mutation of the production system of our society, and so the mutation of the city, is really remarkable here. In the north of Marseille, we observe a lot of old buildings left abandoned, often for many years.

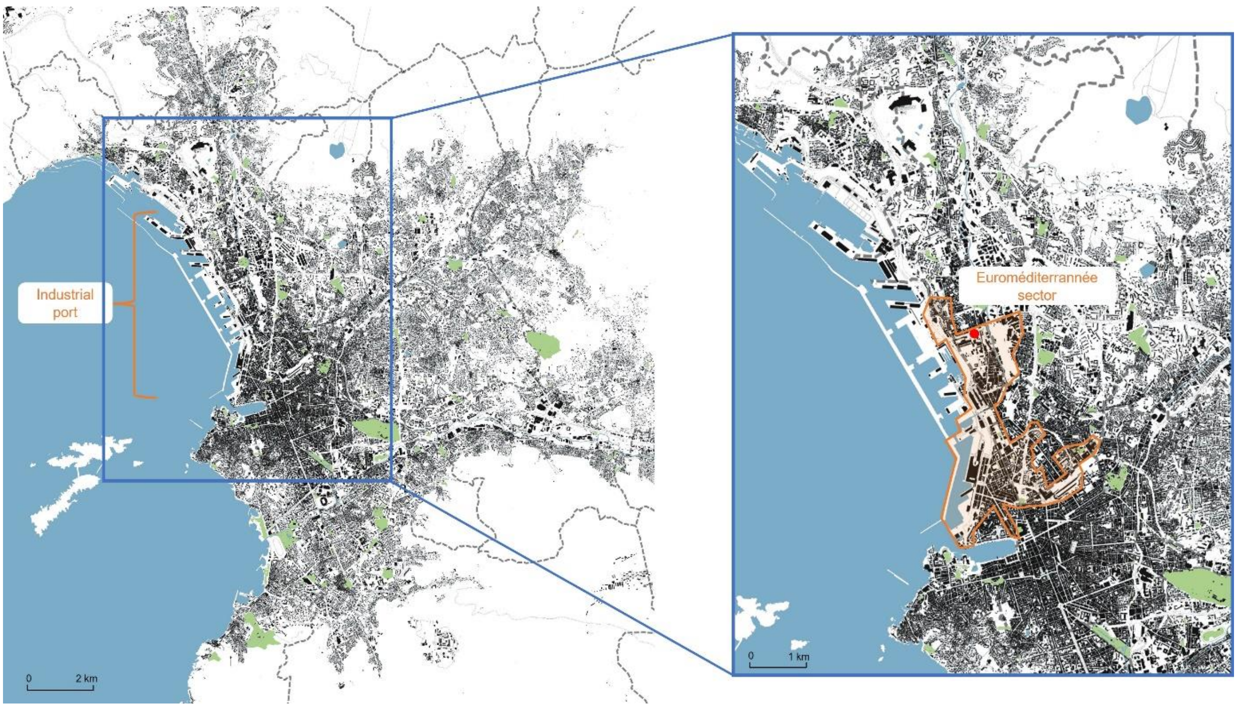


Fig.4: Map of Marseille, with the "Euroméditerrannée sector" in orange, and the building indicated by a red dot

A huge project of urban renewal has been initiated in 1995, the project "Euroméditerrannée", which aims at redeveloping a 650 hectare area to adapt the city to news demands. But unfortunately, for now, it has always implied demolishing old industrial areas to install big residential buildings.

The building we have chosen for our study is an old covered market, known in French as "les Halles Slimani". It is located just at the border between the project Euromediteranée zone and the continuation of the old city. It is an historical building that represent an important heritage of Marseille. Therefore, the city council, owner of the building, wants to protect it from demolition and is waiting for interesting proposals to give a new life to the structure. Thus, after discussion with different actors of the Marseille's urbanisms and members of the city council, this brownfield appeared a very interesting object of study because a process of transformation has already started but there is no project defined yet.

About the neighbourhood, the building is integrated in a quite complicated environment. In fact, it is located in a poor area of the city, separated into residential and industrial areas, without a lot of vegetation. Moreover, it lies at the border of this knew neighbourhood of "Euroméditerrannée" that might be finished in 2026 and welcome a very different population with residential and tertiary uses.

Fig.5: View of the neighbourhood, with the flea market and the industrial port

The *Halles Slimani* adjoins the huge flea market of Marseille **(Fig. 5)**. This 4 hectares market, opened in 1988, is a place for many people to sell second-hand products, and fixed stand to sell food installed in a covered market. This flea market plays a significant social function in the neighbourhood, and the entire city. It welcomes 25 000 visitors during the week and up to 30 000 people a day on Sundays. Therefore, it is also an economically interesting location for a future project because of the large number of people who come to this close place.

3.2. Brownfield characteristics

The *Halles Slimani* was an important slaughterhouse in the city and the historical butchery of the flea market. As it was the only halal slaughterhouse of the department, in a city with a significant immigrant muslim population, the *Halles Slimani* played a really important role and had a huge daily production. Therefore, it was a significant economic actor of the city before it was closed in 2016 after various scandals.

Fig.6: View of the land, the old factory and the two annex buildings

The land is separated into four different parts, as shown in **Fig. 6:**

- The principal building of 1814 m^2, with a typically industrial architecture as visible in **Fig. 7** In this huge building, constructed around 1996, was made all the transformation process of the meat.
- Two separated buildings that were constructed more recently to install the office activities and other support functions.
- A 2200 m^2 opened area, covered with bitumen, partly used for car parking.

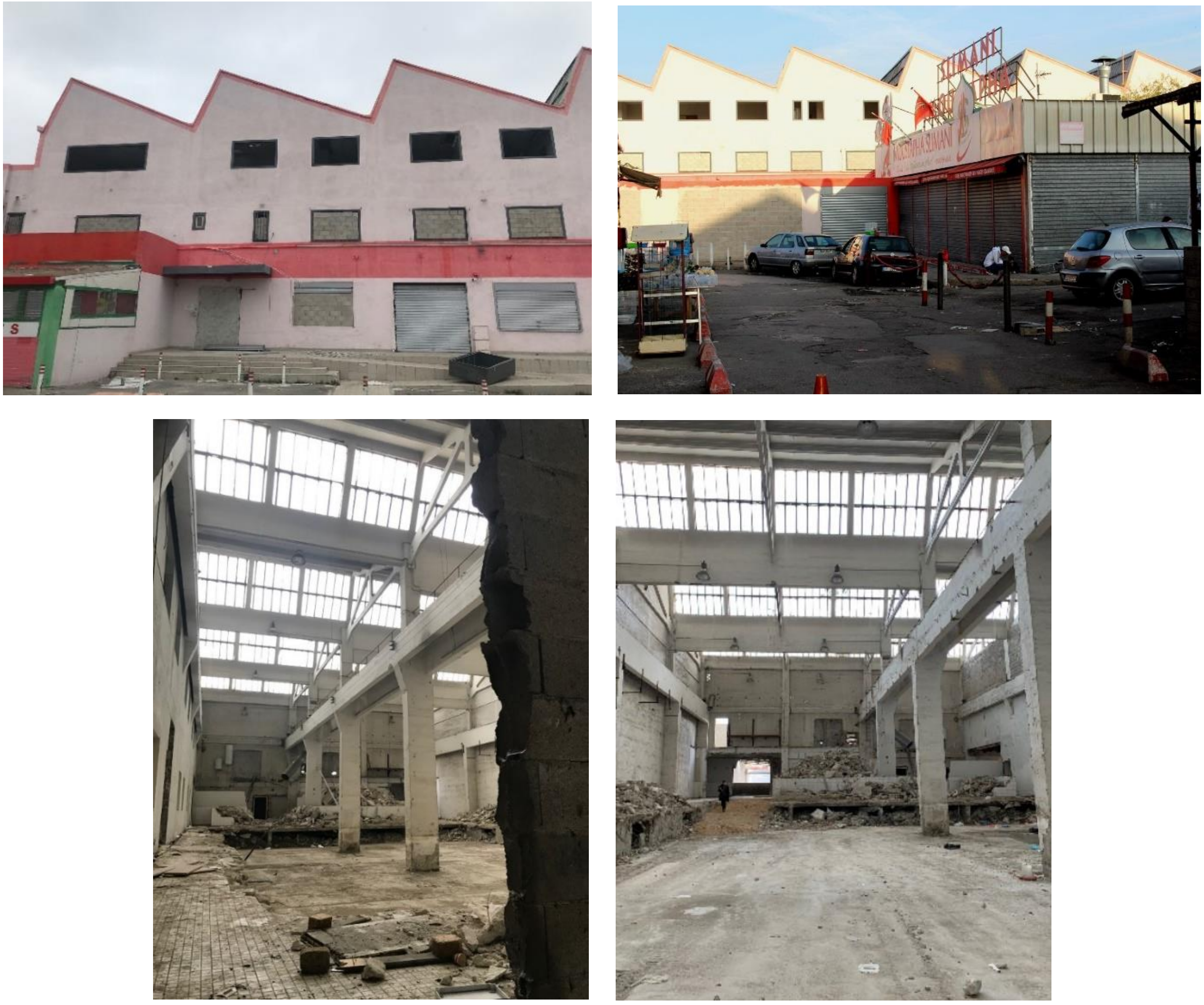


Fig.7: Pictures of the outside and interior structure of the study building (personal source)

We will only focus on the principal building's structure because the two other buildings present a low potential and do not have the patrimonial value of the big one. In addition, in the actual discussions of the city council about the rehabilitation of the place there are planned to be demolished.

Pictures on **Fig. 7** were taken inside and outside of the building and give a view of the structure. It is characterized by a full concrete structure, with particularly large concrete piles. The slaughterhouses have the particularity of having a drilled floor, which was demolished at the end of the activity, to open the floor on a huge pit.

3.3. Alternatives studied

The purpose of the case study is to consider the future of this abandoned building by selecting different possible uses and evaluating each alternative with the MIVES method. To this end, we did a benchmark of the developed project on the French territory, especially in big cities, that have been referenced by the CEREMA in their specific site "Cartofriches" (CEREMA, 2021). Various models are prevalent and we defined the alternatives from the most common projects and the ones that we consider particularly interesting. Therefore, the alternatives studied are:

- Alternative 1: Demolition of the old structure to build residential buildings
- Alternative 2: Demolition of the old structure to build office buildings
- Alternative 3: Reuse of the old structure to welcome companies offices
- Alternative 4: Reuse of the old structure for cultural projects
- Alternative 5: Reuse of the old structure for mixed uses (third-place model)

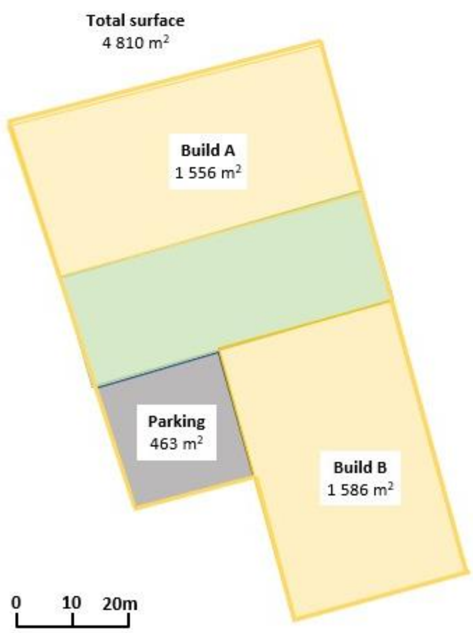
The partition of the area, between artificial soil and green space, between the different activities are detailed in **Table 1**.

Table 1: Alternatives description

Alternative	Demolition	Artificial area (m^2)	Green space (m^2)	Housing	Office activity	Commercial activity	Public services	Cultural services	Restaurant, coffee…
				Gross area (m^2)			Number of structures		
Alt. 1	Yes	3 605	1 205	21 994	-	-	-	-	-
Alt. 2	Yes	4810	0	-	19 422	2 937	-	-	300
Alt. 3	No	4810	0	-	4910	-	-	-	300
Alt. 4	No	4810	0	-	1514	-	-	1814	300
Alt.5	No	3628	164		1214	-	1514	600	300

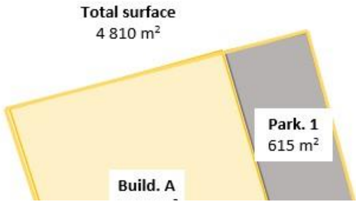
Alternative 1

Figure 8: Alternative 1's plan



The first project is the construction of two new residential building on the brownfield land. The two buildings have a floor area of 1 556 m^2 for Building A and 1 586 m^2 for Building B, as shown on **Fig. 8**. They both have six floors, for a total growth area of respectively 10 892 m^2 and 11 102 m^2, to welcome about 740 people.

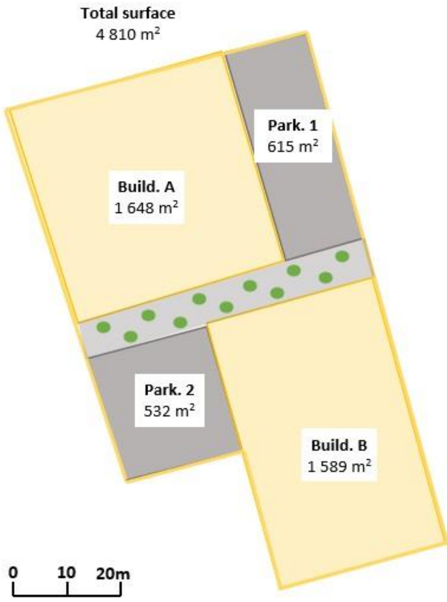
About the structure, the structural parts, walls and floor are constructed in concrete, because of its resistance property and interesting cost. The roof is covered by brick that have a lower environmental impact than steel or slate.



The rest of the land is used for a car park, and a part of the impermeable soil between the two buildings is restored to create a shared garden, with playing area for children.

Alternative 2

Figure 9: Alternative 2's plan



The second project is for tertiary activity, with construction of two office buildings of 1,589 m^2 and 1 648 m^2, as shown in **Fig. 9**. As in the previous alternative, the buildings have six floors, as it has mainly been done in the recent renovation of the "Euroméditerrannée" project. The capacity of the two buildings is about 1300 people. The ground floors of each buildings are used to propose eight shops, and a restaurant.

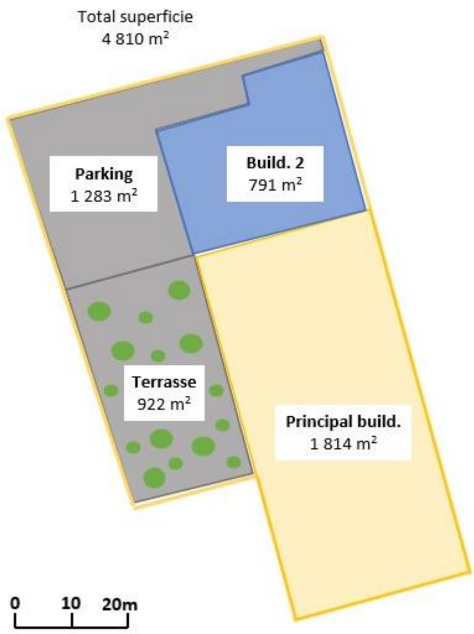
The materials used for the structure of the buildings are the same as in the previous alternative.

Each building has its own parking area. In addition, in the path between the two buildings, vegetation is installed and trees are planted to create a pleasant space to rest. Nevertheless, the soil remains coated as in its original state.

The next projects propose to reuse the initial structure, to avoid the demolition of the building and the huge production of construction waste that it generates. The idea is to propose new uses that matches with the mutation of the city and the increasing population. As the ceiling, height of this industrial building is high, a floor will be constructed to add a second floor and double the usable area. With the reconstruction of the previous floor above the pit, there are the only construction works performed. To be integrated to the actual concrete structure, the two floors will be constructed in concrete as well.

Alternative 3

Figure 10: Alternative 3's plan



Alternative 3 propose to welcome organisations offices, such as little companies or associations. The diversity of the structures facilitates rewarding interactions between different business sectors. The building include a restaurant to open the space on the neighbourhood, and propose a new service for its residents.

The two annex buildings are kept and used also for offices, because there were already dedicated for this use before. This makes a total gross floor area for the installation of the offices (and the restaurant) of about 5 200 m^2.

The unbuilt area isn't constructed and remains covered. A part is used for a parking and the rest of the space is vegetated, furniture such as tables and benches are installed to rest, a terrasse is opened for the restaurant.

Alternative 4

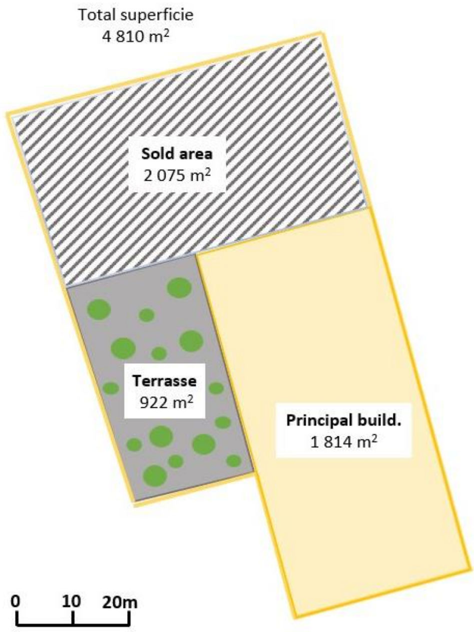
The fourth project propose to use the slaughterhouse building for cultural activities. As it is scheduled in the actual discussion of the city council about the future of the building, the two annex buildings are demolished. In fact, they do not have particular patrimonial interest. The idea of this project is not to build new buildings but exploit the existing one. Therefore, a part of the outdoor area will be maintained, but a 2000 m^2 area, including this two recent buildings, will be sold to welcome other construction project led by another organisation. It allows to create an economic background, to propose services with low price, which is an important advantage in the cultural sector.

The space in the principal building will be divided in 4 spaces: an exhibition hall of 914 m², a music hall of 900 m² to welcome concert and other events, an artistic residency and a restaurant of 300 m².

The unbuilt area welcomes team, tables, places to rest and meet with other people and the terraces of the restaurant.

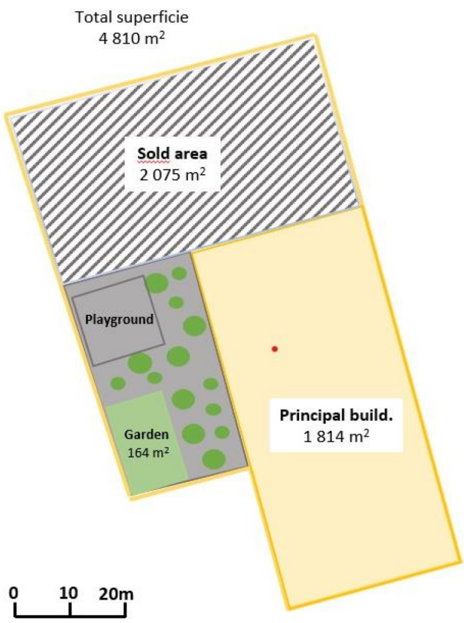
The idea of integrating a restaurant and other recreational structures is to attract people whose curiosity may lead to discover the place and so expand the access to cultural programme to a wider population.

Figure 11: Alternative 4's plan



Alternative 5

Figure 12: Alternative 5's plan



The last project gathers various structures with different uses. The objective is to propose services that are missing in the neighbourhood and to provide social diversity by creating interactions between people who come to enjoy different functions of the building.

As in the previous alternative, the same 2,000 m² area, including the two annex buildings, are sold to be managed by another organisation.

Therefore, we will find:

- Public services such as a nursery of 700 m² and a library of 700m².
- Recreational structures (600 m²)

- A residency of businesses and associations offices of about 1200 m^2
- A restaurant with a huge terrasse (300 m^2 indoor)

Outside of the buildings, a part of the area is uncovered and dedicated to the development of a garden taken care by neighbours. On the covered area, a playground is installed and people are free to appropriate the rest of the area such as a public space.

At first, we had considered an other project that consisted in restoring completely the area to introduce vegetation and create a green space in the neighbourhood that suffers from a lack of vegetation. Nowadays, different remediation technics exist and are well referenced to restore contaminated soils. They remain expensive methods, but those projects become present in cities to propose a response to the lack of green spaces. In addition, because we know the positive effects on the well-being and health of the citizens as it contributes in catching polluting emission and creates islands of coolness. Particularly in the neighbourhood studied, it could be a very interesting alternative, but we chose not to explore it because the environmental impact is overly low compared to the other projects and it would have distorted the results.

4. ASSESSMENT METHOD

4.1. Decision-making tree

The decision-making three is the foundational part of the MIVES method. For this study, the tree was designed from economic, environmental, and social requirements, according to the three pillars of sustainable development defined by the UN. These requirements are divided into 7 criteria and 15 indicators as showed in **Fig. 13**.

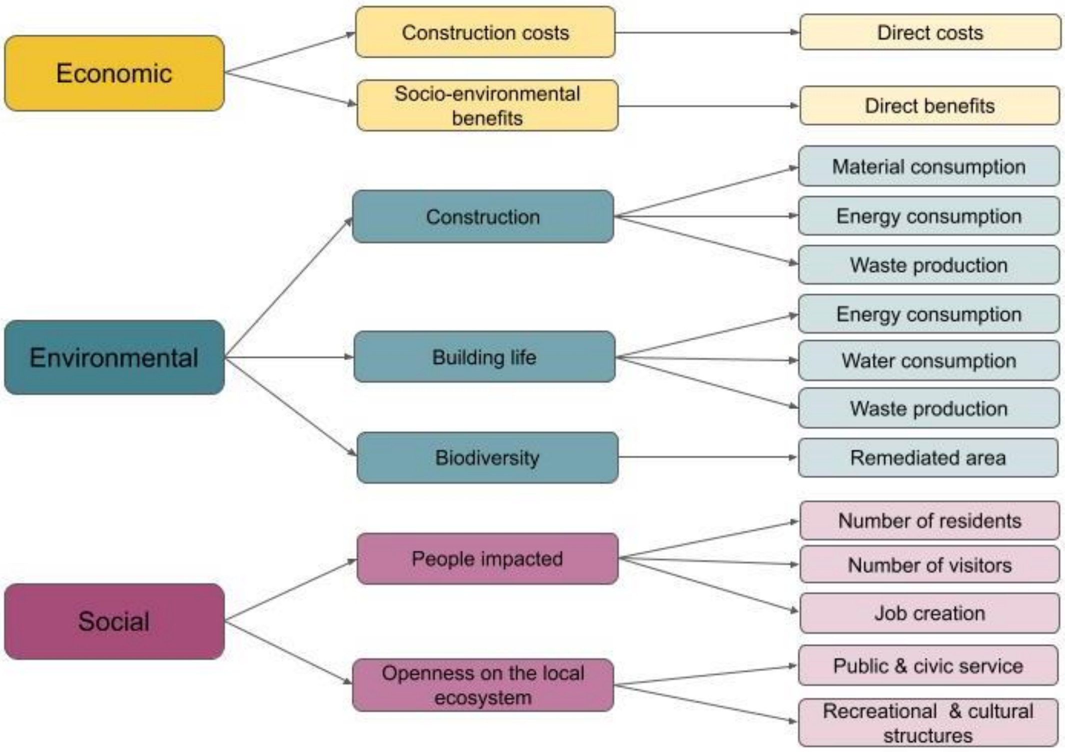


Fig.13: Decision-making tree model for the study case

Economic requirements

- *Construction costs*

  The direct costs of the construction project first refer to land acquisition costs and engineering studies costs to do a prior identification of the contamination level of the site. During the renovation and construction processes, direct costs refer to materials, labour, equipment, and power costs needed for the different phases: decontamination, demolition and construction of the building (for re-construction) or of structural parts to reorganize the space (for re-use).

- *Direct benefits*

  Direct benefits for the city and brownfield environment refer to the value created by the decontamination and creation of a new function: economic benefits of recreational and cultural infrastructure, introduction of green spaces consequences (pollution mitigation, island of freshness, public health) (Chateau et al, 2021).

Environmental requirements

- *Material consumption during construction*

  In the case of re-use, the indicator assesses the environmental impact of materials used for the reorganization of the building, that is to say the partition of areas and the construction of new spaces. In the case of re-construction, the indicator also refers to all the material used to build the structure of the new building. The indicator is calculated in tCO_2eq to better represent the impact of the use of resources and valorise projects that make the choice to prefer low impact materials (eco-materials, recycled, reused) to conventional construction materials.

- *Energy consumption during construction*

  This is the energy necessary to make the equipment work during the construction period (without the deconstruction). We do not consider lighting and heating consumption in this phase that is less significant. In addition, we do not assess the energy consumption of the demolition process neither.

- *Waste production during construction*

  In the case of re-use of the origin building, the wastes produced are the structural materials demolished to restructure the space. Moreover, in the case of demolition and reconstruction of a new building, the wastes are all the materials forming the old structure.

- *Energy consumption during life*

  The annual energy consumption is the electric consumption of the building for lighting, the use of electronic devices, but also building heating, the use of gas in the case of a restaurant, etc. If a part of the energy consumed comes from a renewable energy source, this part is not counted in the global consumption of the building.

- *Waste production during life*

  The indicator only assesses the quantity of wastes produced that are not valorised and finishes in incineration plants or landfills covered. The objective with this method is to value the projects that make efforts to do a good waste sorting, or recycle the wastes they produce.

- *Water consumption during life*

  This is the annual water consumption of the building for the various uses.

- *Remediated area*

  The reintroduction of green spaces and the reduction of the soil sealing on site have a direct effect on the biodiversity. The indicator measures the part of the land that has been remediated.

Social requirements

- *Number of residents*

  The residents of the building are the people working on site for the businesses and organizations installed there. They can also be people living there in residences, social residences, or welcome places for people in need run by associations. They are the people directly and significantly impacted by the project.

- *Number of visitors*

  This is the number of people who visit the site during the year, for specific events, to enjoy activities organized by the structure, to eat on site, and for all other uses proposed for people from the outside. This indicator is important too to have an idea of the diversity of the people and the opening of the building on its neighbourhoods.

- *Job creation*

  The number of people working for the site manager organization, whether it is a full-time job or part-time job. Job created can be cleaning and maintenance of the building and exterior for a residence, sailors and managers of commercial premises, host and reception, etc. We measure it in Full Time Equivalent (FTE).

- *Public & civic services*

Brownfield redevelopment projects can offer a solution to a missing service in the neighbourhood or in the city. In fact, it is common that we find public services such as nurseries, libraries, post offices. Therefore, this indicator counts the number of this public services but also civic services, as social insertion infrastructures.

- *Recreational & cultural structures*

  The site can also become a place of entertainment for internal and external public. We count the number of sport equipment and of infrastructures offering a cultural programming such as an exhibition hall, a concert hall, a scene.

4.2. Value function

The MIVES method uses value functions to convert indicators values with different units into normalised values between 0 and 1 (Pons et al, 2021). The specific value function used in the methodology can take different forms: increasing or decreasing linear, concave, convex or S-Shaped, as shown in Figure 5. The mathematical expression of the value functions corresponds to the Equation 1:

$$V_{ind}(X_{ind}) = A + B\left[1 - e^{-K_i(\frac{|X_{ind}-X_{i,min}|}{C_i})^{P_i}}\right] \quad (1)$$

$$B = \left[1 - e^{-K_i(\frac{|X_{max}-X_{min}|}{C_i})^{P_i}}\right]^{-1} \quad (2)$$

Where,

- X_{min} is the value of the indicator with the worth satisfaction (index value = 0) and X_{max} with the best satisfaction (index value = 1). When X_{min} > X_{max}, then the function is decreasing, if not it is increasing
- X_{ind} is the value of the indicator for the alternative assessed,
- A is the value of V_{ind} for X_{min},
- P_i determines the shape factor that defines if the function is linear (P_i =1), concave ($P_i < 1$), convex ($P_i > 1$), or S-shaped curve ($P_i > 1$),
- C_i is the approximated point inflexion abscissa,
- K tends toward $V_{ind}(X_{ind})$

- B is the factor that prevents the function from exceeding the range (0-1), and defined by Equation (2).

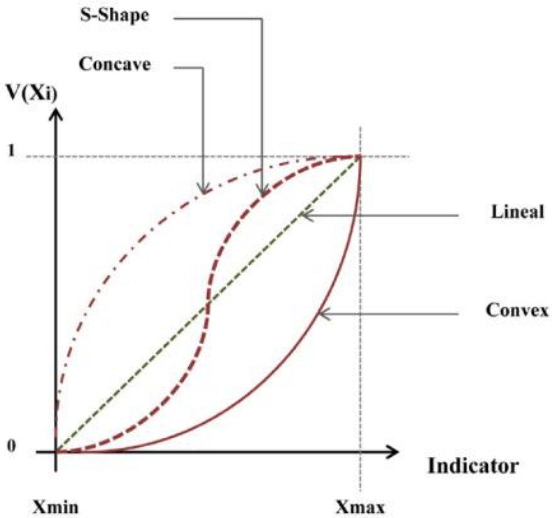


Figure 14: Value functions shapes (Josa et al.)

In the decision-making tree, each indicator is assessed with a particular unit and has its own shape. Therefore, the value functions parameters were determined for the 15 indicators and are resumed in **Table 2**. The following criteria were used for defining the value function shape and the abscissa limits for each indicator:

- *Direct costs (I1)*. We take as a reference the first alternative, so the case of a demolition and construction of two residential buildings. Based on this it is assumed that the minimum satisfaction is reached for increase of 25% with respect to the reference values (Ministère de la transition écologique, 2022). The reference case leads to a satisfaction of 0.5. We choose a decreasing S-shaped function to represent the fact that beyond a determined value the satisfaction decreases rapidly, and the project becomes unfeasible.
- *Direct benefits (I2)*. The value function here is an increasing concave function. We choose this form because there may be an important difference between the index values of the alternatives. Moreover, a concave function has the advantage to value all the efforts, even the smallest ones, and not neglect the value for the city of small projects.
- *Environmental indicators during construction (I3,I4,I5)*. The same reference project as previously is chosen. Nevertheless, the potential for progress is higher, due to the low impact of the rehabilitation projects. Therefore, the maximum satisfaction is achieved for a null index

value, and the minimum satisfaction for an increase of 25% with respect to the reference. The reference project satisfaction is 0,5. (Coelho et al, 2012) (Villora et al, 2020). A decreasing concave function is the most adapted shape here, because below some level the environmental impact of the construction is normal and allowed without any issues.

- *Environmental indicators during the building life (I6,I7,I8).* For the annual environmental impacts, some quantity of energy, water and waste is needed to make the building activity works, but in a context of energy efficiency concern, it is not acceptable to exceed a mean consumption of the sector. Therefore, decreasing S-shaped functions are the most representative here. Here again, depending on the size of the buildings, there can be an important gap between the different projects values. Thus, the reference project satisfaction is defined as 0.5. The minimum satisfaction is reached for an increase of 25% (ADEME, 2022) (EC, 2022).
- *Biodiversity (I9).* The satisfaction of the remediation of the area to introduce green spaces increases linearly until it reaches 100% of the area. We assume that an area can only welcome new diversity when real garden plots with a significant superficies are created.
- *Social indicators(I10,I11,I12,I13,I14).* All the value functions are increasing linear functions. For the number of residents, the best satisfaction is defined considering the case of the construction of an office building, that welcomes the highest density of population, 15m^2/employee (Norm AFNOR NF X 35-102). For the other indicators, we chose as a reference the existing project La Friche Belle de Mai in Marseille (La Friche Belle de Mai, 2019), because it is seen as a very good success example and it has a high diversity of functions. Obviously, it is reported to the scale of the *Halles Slimani*, about twelve times smaller. To represent the potential of progress, it is chosen that the satisfaction of this reference project is 0.80. Linear functions are used not to give an equal value to all the people participating to the project and all the structures welcomed in the building.

The graphic representations of all the value functions are represented in the **Annex 1**.

Figure 15: La Friche Belle de Mai, an inspiring project in Marseille, France

Table 2: Parameters of the value functions

Requirements	Indicators	Units	Function	Xmax	Xmin	C	K	P
Economic	I1 Direct costs	M€	DS	33	1	30	40	2
	I2 Direct benefits	€/year	ICc	0	60	80	2	1
Environmental	I3 Material consumption	tCO2eq	DCc	6000	0	4000	2	1
	I4 Energy consumption	MWh	DCc	4300	0	2500	2	1
	I5 Waste production	T	DCc	8250	0	5000	2	1
	I6 Energy consumption	MWh/year	DS	7750	1000	15000	40	3
	I7 Water consumption	m3/year	DS	44000	1000	60000	40	2.5
	I8 Waste production	t/year	DS	400	25	600	40	2.5
	I9 Remediated area	% space	IS	0	50	35	3	3
Social	I10 Number of residents	Un	IL	0	1600	1	0	1
	I11 Number of visitors	mun/year	IL	0	63	1	0	1
	I12 Job creation	Un	IL	0	22	1	0	1
	I13 Public & civic services	un	IL	0	4	1	0	1
	I14 Recreational & cultural structures	un	IL	0	5	1	0	1

It is important to notice that the parameters of the value functions are specific of the present case study. They have to be adapted to each brownfield sites to be evaluate, because they can have very different typology and sizes. However, the indicators and the following weight attribution always remain valid.

4.3. Weight assignment

To determine the weights of the requirements, criteria and indicators a proportion method was used, attributing directly a weight to each component of the decision-making tree.

Table 3 : Weight distribution

Requirements	w (%)	Criteria	w (%)	Indicators	w (%)
R1 Economic	20	C1 Construction costs	20	I1 Direct costs	100
		C2 Socioenvironmental benefits	80	I2 Direct benefits	100
R2 Environmental	40	C3 Construction	50	I3 Material consumption	40
				I4 Energy consumption	40
				I5 Waste production	20
		C4 Building life	30	I6 Energy consumption	40
				I7 Water consumption	40
				I8 Waste production	20
		C4 Biodiversity	20	I9 Remediated area	100
R3 Social	40	C5 People impacted	70	I10 Number of residents	60
				I11 Number of visitors	10
				I12 Job creation	30
		C6 Openness on the local ecosystem	30	I13 Public & civic services	50
				I14 Recreational & cultural structures	50

A few professionals of French local administrations (at departmental levels) were invited to participate to a survey. They were people in charge of the selection of the brownfield redevelopment projects that will receive subventions in their territory. The participants were chosen because it is the point of view that we want to take in the study but results may change a lot depending on the person evaluating the project. Therefore, considering the level of uncertainty, a sensitivity analysis of the sustainability index was carried out considering other weight distributions in section 5.

4.4. Quantification of the indicators

To determine the value of the indicators for each alternatives different sources are used.

First of all, the value of the two economic indicators are directly extracted from the tool Benefriche (Chateau, 2020). It is an open-access Excel, developed by ADEME, the environment and energy management agency in France. From the characteristics of the old and new buildings, such as area, uses, partition of the space, the Excel calculates the project costs and benefits for the city.

For the environmental impact of the construction process, we use data from INIES, the national database for environmental data of the construction sector (INIES Database, 2022). Each square meter of the building elements is associated to its impact (energy consumption, emission factor, etc), depending on the material **(Annex 2).** Therefore, knowing the structure of the future building, I3 and I4 indicators can be calculated. Moreover, for the environmental impact of the operating phase, we used mean values of energy and water consumption and waste production in France, for the different building typologies (residential, offices, commercial, cultural, etc).

Table 3 : Value of indicators for each alternatives and indicators

Indicators	Units	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
I1 Direct costs	M€	28.9	30.8	2.8	1.8	1.8
I2 Direct benefits	m€/year	26.2	2.16	16.3	48.7	48.2
I3 Material consumption	tCO2eq	4849	4862	140	95	105
I4 Energy consumption	MWh	3575	3513	130	69	83
I5 Waste production	t	6609	6609	0	0	0
I6 Energy consumption	MWh/year	4178	6253	1437	1001	1001
I7 Water consumption	m3/year	35 190	14 015	10 462	1762	8326
I8 Waste production	t/year	321	183	57	28	25
I9 Remediated area	% space	25	0	0	0	3
I10 Number of residents	un	733	1294	327	101	81
I11 Number of visitors	mun/year	0	15	15	35	51
I12 Job creation	un	1	20	5	5	12
I13 Public & civic services	un	0	0	0	0	2
I14 Recreational & cultural structures	un	1	0	0	3	5

The social indicators come directly from the definition of the different alternatives, the area dedicated to each function of the buildings and so the capacity of each group of persons.

From all this sources, we calculate the value of the indicators; the results for each alternative are sumarised in **Table 3**.

5. RESULTS AND DISCUSSION

Finally, with the value functions and weights of all the elements, we obtained the total sustainability score of the different projects considered, that are resumed in **Table 4**:

Table 4 : Final results

	Alternative	Final index value
1	Construction of 2 residential buildings	**0.40**
2	Construction of 2 office buildings	**0.33**
3	Re-use of the old structure for tertiary activity	**0.44**
4	Re-use of the old structure for cultural activity	**0.62**
5	Re-use of the old structure to welcome a third-place	**0.72**

So, with the method and arguments we drew previously, the project of installation of a third-place in the *Halles Slimani's* old structure mixing uses, is the more sustainable with a final index value of 0,72. The project of re-use of the old structure to develop cultural activity and propose a place of recreation in the neighbourhood has also a good sustainability score of 0.62. The other projects obtain close final values but below the two previous, around 0.40.

Table 5 : Index values detailed for each alternatives and indicators

Indicators	Units	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
I1 Direct costs	M€	0.53	0.19	1.00	1.00	1.00
I2 Direct benefits	m€/year	0.62	0.07	0.43	0.91	0.90
I3 Material consumption	tCO2eq	0.46	0.46	1.00	1.00	1.00
I4 Energy consumption	MWh	0.45	0.48	1.00	1.00	1.00
I5 Waste production	t	0.50	0.50	1.00	1.00	1.00
I6 Energy consumption	MWh/year	0.43	0.04	0.97	1.00	1.00
I7 Water consumption	m3/year	0.28	0.51	1.00	1.00	1.00
I8 Waste production	t/year	0.23	0.45	1.00	1.00	1.00
I9 Remediated area	% space	0.67	0.00	0.00	0.00	0.00
I10 Number of residents	un	0.48	0.82	0.22	0.07	0.05
I11 Number of visitors	mun/year	0.00	0.23	0.23	0.55	0.81
I12 Job creation	un	0.05	0.91	0.23	0.23	0.55
I13 Public & civic services	un	0.00	0.00	0.00	0.00	0.50
I14 Recreational & cultural structures	un	0.20	0.00	0.00	0.60	1.00

To understand those final scores, it is important to make a detailed analysis of the results. Therefore, the index values of all the indicators are presented in **Table 5**.

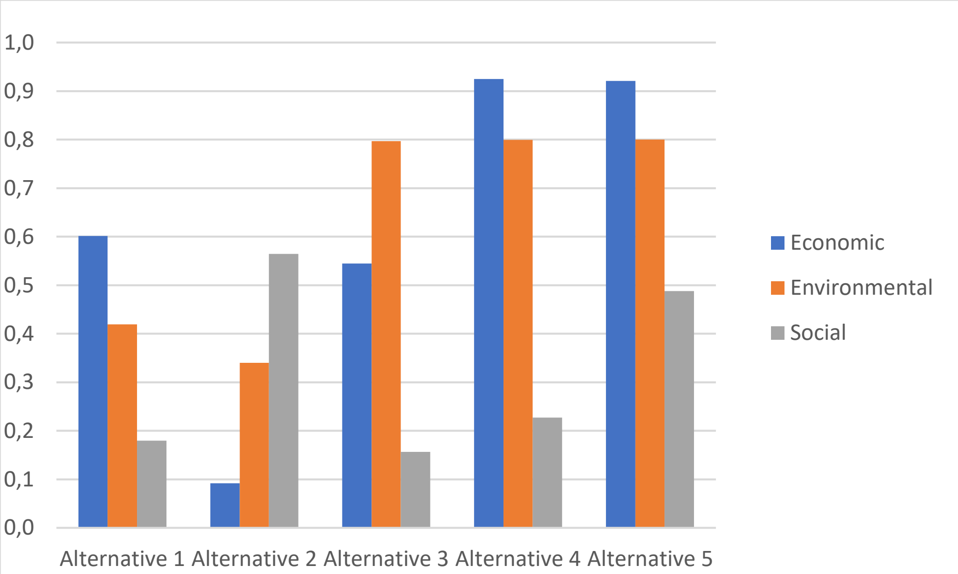
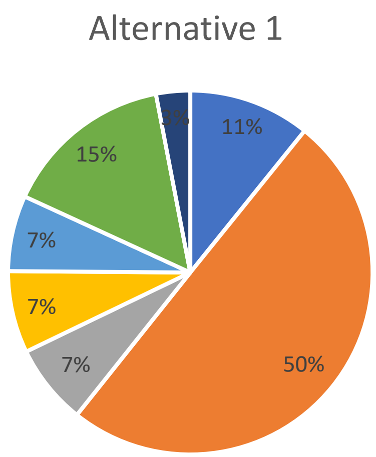


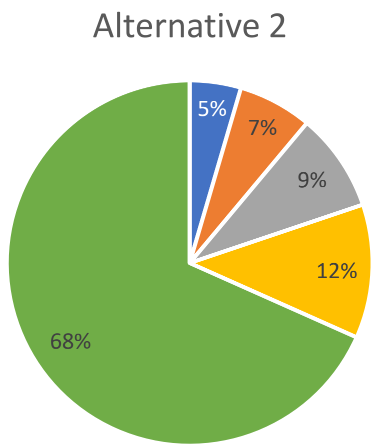
Figure 16: Score of the 3 requirements for each alternative

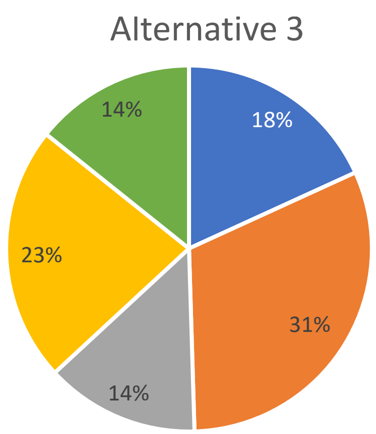
First of all, we can compare the economic, environmental and social score of each project and observe that **(Fig.16)**:

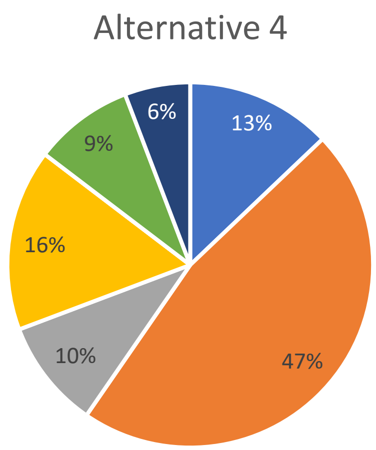
- Alternative 4 and 5 have the best final score because they accumulate the best score both for economic and environmental requirements. It is not a surprise for the environmental impact of the projects that is verry low thanks to the reuse of the old structure. And also because a part of the space is not studied, because sold. Hence, the global environmental impact of the reconstruction will depend also of the project drawn in the rest of the land. However, considering the definition of the scope of the study, we only considered the first project and we have to be attentive in the discussion of the results.
- Similarly, the good economic score of the two projects is due, in part, to the sale of part of the space. Nonetheless, the high economic value is also a consequence of the variety of uses, the number of people who take advantage of this place. It is because we chose to value socio-environmental benefits and not all economic benefits for the city, which would have valued the alternatives including commercial and tertiary activity.
- Of course, because of the scale of the projects, the first two alternatives are disadvantaged in the economic analysis.

- The three alternatives of rehabilitation, and reutilisation of the old structure (alternative 3,4 and 5) have the best score because they limit the creation of construction waste and the use of new materials during the construction process. In addition, owe to the the size of the project is less important, what reduces incoming and outcoming flows during the building life.
- Alternative 2 have the highest social score. It is mostly due to the job creation of commercial activity, and the number of people concerned, since many people use the place every day, than occasionally.
- Alternative 1 and 3 have more or less the same score. Nevertheless, in the case of the alternative 3 it is mostly due to the reuse of the building, that is very positive for the environment. The construction of two residential buildings is also an interesting alternative because of the creation of a green space for resting and recreational activities.









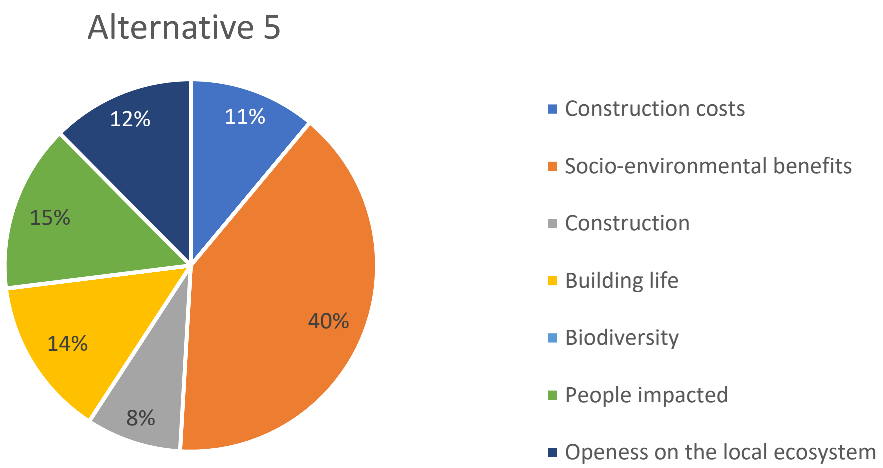


Figure 17: Contribution of the different criteria in the final sustainability evaluation

If we have a look more in detail on the criteria share in the final graduation, we can do additional comments:

- Except for the office buildings construction project, the socio-environmental benefits is the indicator that contribute the most to the sustainability of the project, from 31% to 50%.
- For alternative 2, 68% of the final score of the project is due to the number of people impacted. Mainly because the two large office buildings can welcome many workers, and because the commercial activity attracts people from outside.
- The place of environmental arguments in our study is relatively weak. However, this is mainly due to the weight attribution that evaluates it as the less important criteria for the public institutions involved in this kind of projects.

But people reading this study have to be aware that it is based on an assumed position and a personal point of view, that valorise the social benefits of a cultural activity more that the wealth created by economic activity. Because we consider than structures with a social or cultural project are important for the health of a city. Their existence favours the well-being of the citizens, develops social diversity, makes the city more attractive and increases the economic attractivity. However, it seems that nowadays, more and more cities share this vision, and we see in the territory lots of, at first temporary projects, becoming long-term projects because they have proven their efficiency and socio-economic impact.

Moreover, this study chose to take the point of view of public institutions involved to select the projects of interest in their territory. This vision gives an important weight to the socio-environmental benefits in the study, what participates to the place on the podium of the two last alternatives, and the worst score for the construction of office buildings project.

Besides, the environmental impact of the project during its use depends a lot on the practices of the residents and of the site owner. The installation of sources of renewable energy, such as photovoltaic panel on the roof, or an efficient thermic isolation can reduce the impact of energy consumption. And the establishment of good practices for wastes management can increase the valorisation of part of the wastes produces by the site activity.

Obviously, we selected different categories of projects, the most commons but also the ones that we consider interesting, and it is not an exhaustive list. Renaturation project could be a really interesting solution, particularly in this very industrialised neighbourhood. Likewise, in a context of global warming, it is a solution that is more and more explored in big cities. Brownfields can also be places of experimentation: because city councils can make them available for low prices, that rehabilitation project are quite recent, many structures are already experimenting new models in all the French territory.

Finally, we can see some limits with the analysis model we developed. Due to the huge diversity of the alternatives we can question the reliability of the results. In fact, for some indicators, index values can be close to 1 for some alternatives and close to 0 for other, what makes the global score very dependent on the weight attributed to the indicators.

Moreover, the model we developed can only be used for this particular project. We did not succeed in constructing a universal model directly applicable to any brownfield sites. Even if the indicators remains the same for other projects, the value function parameters have to be defined for every brownfield site we want to study.

6. SENSITIVITY ANALYSIS

In the approach taken for all the study, we only considered a particular perspective, attributing a relative importance to each indicators. However, the variability of viewpoints should be included to test the robustness of the results and the validity of the conclusions. So we choose to focus on the uncertainties of the weighting system, that is only the result of the perspective of two experts. So we analysed the indicators value for different weight attribution to measure the influence of weighting.

The sensitivity analysis considers two extreme cases (**Table. 5)**:

- A period of recession for the city, or the case of a city with low wealth. The economic requirement would become essential and represent a weight of 80% in the decision-making.
- Countries with a high sensibility for environmental issues, such as Nordic countries, or organisations with an environmental perspective. The study would give a heavier weight to environmental and social requirements, as both are often related.

Table 5 : Weight attribution for sensitivity analysis

Recession situation				**Country with environmental concerns**			
Requirements	**w (%)**	**Criteria**	**w (%)**	**Requirements**	**w (%)**	**Criteria**	**w (%)**
Economic	80	Construction costs	70	**Economic**	80	Construction costs	80
		Socioenvironmental benefits	30			Socioenvironmental benefits	20
Environmental	10	Construction		**Environmental**	10	Construction	50
		Building life	50			Building life	30
		Biodiversity	20			Biodiversity	20
Social	10	People impacted	70	**Social**	10	People impacted	70
		Openness on the local ecosystem	30			Openness on the local ecosystem	30

Table 6 : Final index values for new weight attributions

	Alternative	**Recession situation**	**Countries with environmental concerns**
1	Construction of 2 residential buildings	**0.51**	**0.44**
2	Construction of 2 office buildings	**0.21**	**0.45**
3	Re-use of the old structure for tertiary activity	**0.76**	**0.65**
4	Re-use of the old structure for cultural activity	**0.88**	**0.76**
5	Re-use of the old structure to welcome a third-place	**0.91**	**0.86**

The results summarised in the **Table 6** show that, whatever the weight are distributed differently, it will not change the ranking of the projects the most sustainable. In a case of a recession or for a city with economic difficulties, the project of demolition and reconstruction would not be more interesting because of the high cost of the construction process. The projects of reuse of the old structure would remain more sustainable, even if we consider the environmental arguments almost inexistent. If we value environmental and social indicators, the two first projects of demolition still have the worst results. Nevertheless, the alternative of construction of offices buildings increases its score because job creation and number of people impacted by the projects give the project a good social impact.

The reason is that project with low environmental impact are also the ones more attractive financially. Therefore, whether we value environmental concerns or economic ones, the same projects would remain the most sustainable. Only the final index values would change.

Finally, this sensitivity analysis is important because it highlights the robustness of the previous results. In fact, it shows that even if we change the perspective and actor concerned the ranking remains the same; and so prove the objectivity of the model built.

7. CONCLUSIONS

The present study proposed to compare the sustainability of different redevelopment projects for old abandoned industrial buildings, with deconstruction of the old structure or reuse, and proposing various uses. The model was applied to a study case, the Halles Slimani, an old slaughterhouse in Marseille left abandoned about ten years ago. This study allowed us to draw some conclusions on the subject:

- The Sustainability Index (SI) derived from the application of the MIVES method, evidenced that the alternative 5 (SI = 0.72) is the most sustainable alternative for the set of weight established.
- Projects that propose to use the old building structure for a new use are the most sustainable because their environmental impact is significantly low, and because they welcome a diversity of uses and so impact a hight diversity of people.
- A sensitive analysis proved that the alternative 5 remains the most sustainable for different weight distributions. Therefore, the method is not the result of a subjective or particular point of view. It is valid whatever the politic of the project stakeholders is, if the environmental impact is a significant issue or if the cost of a project is the principal argument.
- There are some limits to this analysis model and, due to the huge diversity of the alternatives; we can question the reliability of the results. In fact, for some indicators, index values can be close to 1 for some alternatives and close to 0 for other, what makes the global score very dependent on the weight attributed to the indicators.

Nevertheless, beyond this technical study, that can give interesting base analysis, it is important to consider the particularity of each site, the environment all around it. This is the difficulty of urbanism projects that have a social dimension after all. And in a very poor neighbourhood, as here next to the flea market, the construction of new offices and new apartments, and with it the arrival of a richer population, could create a spatial gap between the old neighbourhood and the new one. And even if a new cultural offer and public services can be really interesting for the neighbours, they have to feel like they can appropriate this place, and this will depend a lot on the organisations leading this projects. To conclude, this analysis is not the assurance of the success of the future projects, lots of other parameters are involved.

The present study as proven that it is possible to build an objective comparison tool to compare different urban redevelopment projects. In addition, this kind of model could be interesting for public institutions to compare different projects proposal and attribute funds to the projects with more impact on the population, for the city and low environmental consequences. Next step would be to build a tool, easy to learn, adaptable to all brownfield sites and with a weight attribution editable to adapt to the city politics.

BIBLIOGRAPHY

ADEME. Déchets chiffres clés. Available at: https://www.ademe.fr/sites/default/files/assets/documents/dechets_chiffres_cles_edition_2020_010692.pdf (accessed on 2 March 2022)

Alberini, A. Longoc, A. Tonind, S. Trombettad, F. Turvani, M. The role of liability, regulation and economic incentives in brownfield remediation and redevelopment: evidence from surveys of developers. *Regional Science and Urban Economics*, **2005**.

CEREMA. Cartofriches. Available at: https://cartofriches.cerema.fr/cartofriches/

Chateau, L., Piquant, M., Bestieu, A., Cauchard, L., Serre, J. Evaluer les bénéfices socio-économiques de la reconversión de friches pour lutter contre l'artificialisation – Outil BENEFRICHES. *Librairie ADEME*, **2020**.

Coelho, A. and De Brito, J. Influence of construction and demolition waste management on the environmental impact of buildings. *Waste Management*, **2012**

LDV Studio Urbain. Les Grands voisins: la ville éphémère investit les espaces intercalaires. *Demain la ville*, **2016** Available at: https://www.demainlaville.com/les-grands-voisins-la-ville-ephemere-investit-les-espaces-intercalaires/

Doick, K. G., Sellers, G., Hutchings, T. R., Moffat, A. J. Brownfield sites turned green: realising sustainability in urban revival. *WIT Transactions on Ecology and the Environment, Vol 94*, **2006**.

El Menchawy, A. Urban regeneration in Mediterranean cities: an integrated urban development of Brownfield sites. *Sustainable city*, **2008**.

European Commission. EU Buildings Datamapper. Available at: https://ec.europa.eu/energy/eu-buildings-datamapper_en (accessed on 2 March 2022)

European Environmental Agency. Progress in management of contaminated sites. Available at: https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites-3 (accessed on 26 november 2021)

Eurostat,Water statistics: Available at:https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics#Water_uses (accessed on 13 April 2022)

France Tiers Lieux. Available at : https://francetierslieux.fr/les-tiers-lieux-en-france/

Government of Canada. About contaminated sites. *Environment and Climate Change Canada.* **2016**

Hammond, E., Coulon, F., Hallett, S., Thomas, R., Hardy, D., Kingdon, A., Beriro, D. A critical review of decision support systems for brownfield redevelopment. *Science of The Total Environment*, **2021**.

INIES Database. Available at: https://www.base-inies.fr/iniesV4/dist/consultation.html (accessed on march 2022)

Josa, I., Toši´c, N., Marinkovi´c, S., de la Fuente, A., and Aguado, A. Sustainability-Oriented Multi-Criteria Analysis of Different Continuous Flight Auger Piles. *Sustainability*. **2021**, 13, 7552.

La Friche Belle de Mai. Rapport d'activité 2019. **2019**

Les Horizons. La dépollution des friches industrielles, un enjeu pour la ville de demain. *Demain la ville*, **2021**. Available at : https://demainlaville.com/la-depollution-des-friches-industrielles-un-enjeu-pour-la-ville-de-demain/

Manual MIVES. Modelo Integrado de valor para evaluaciones sostenibles. **2009**

Ministère de la Transition écologique en France. Economie de la construction. Available online: https://www.ecologie.gouv.fr/economie-construction (accessed on 22 February 2022)

Pahlen, G., Glöckner, S. Sustainable regeneration of European brownfield sites. Brownfield Sites II, **2004**

Payá Pérez, A., Rodríguez Eugenio, N. Status of local soil contamination in Europe. *JRC technical reports for the European Commission*, **2018**.

Pons, O., Casanovas-Rubio, M. M., Armengou, J., and de la Fuente, A. Sustainability-Driven Decision-Making Model: Case Study of Fiber-Reinforced Concrete Foundation Piles¨. *J. Constr. Eng. Manage.* **2021**, 147

Song, Y., Kirkwood, N., Maksimović, C., Zheng, X., O'Connor, D., Jin, Y., Hou, D. Biotechnological Advances for Restoring Degraded Land for Sustainable Development. *Science of the total Environment, Vol. 663*, **2019**.

Tripathi, V., Adil Edrisi, S., Chen, B. K. Gupta, V., Vilu, R., GAthergood, N., Abhlash, P.C. Biotechnological Advances for Restoring Degraded Land for Sustainable Development. *Trends in Biotechnology*, Vol. 35, No. 9, **2017**.

United Nations Environment Programme (2020). 2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.

Available at: https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf (accessed on 3 december 2021)

Van Liedekerke, M., Prokop, G., Rabl-Berger, S., Kibblewhite and M., Louwagie, G. Progress in the Management of Contaminated Sites in Europe. **2014**

Villoria, P., César Porras, S., and Mercedes del Río Merino, M. Estimation of construction and demolition waste. *Civil and Structural Engineering*. **2020**, 13-30

Vermot, T., Morel, C., Reffet, F., Di Benedetto, S. and Cézanne-Bert, P. Le recyclage urbain sous toutes ses formes. **2021**