Heliyon 9 (2023) e19866

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Sustainable services planning. Methods supporting the design of cultural exhibitions

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ARTICLE INFO

Keywords:
Sustainable design
Cultural exhibitions
Sustainability approaches

ABSTRACT

The sustainable design of product systems has been addressed in numerous research works. However, studies regarding the sustainability of services are fewer and they are focused mostly on the study of environmental aspects during the service provision stage. Regarding cultural services, the application of sustainability principles in their design process is increasingly required due to reasons such as environmental awareness, social responsibility, visitors' preferences and innovation strategies. Although up to date a limited number of initiatives have been promoted. The objectives of this work are the description of a specific sustainable design method based on the development of systematic tasks and supported on three complementary approaches, and the application of this method to the design of two different types of cultural exhibitions. The design of an itinerary exhibition, which is developed in a sheltered indoor space, and an exhibition, which is developed in the streets of a big city, are, respectively, carried out. The sustainability performance of different design alternatives are valued in each case by analyzing the incidence of those systems, activities, and stakeholders involved along the entire service development and using not only environmental but also socio-economic indicators. Thus, this research work aims at providing the appropriate methodological support to designers of cultural services and managers of cultural institutions, to carry out more sustainable projects.

1. Introduction

Nowadays, one of the most important challenges for the designers is the effective integration of sustainable aspects in their designs. During the first wave of sustainability, numerous research works have been focused on developing an environmentally friendly or ecological design [1]. Since then, an abundance of tools called eco-design tools were developed to improve products from an environmental point of view. In the current wave of sustainability, a comprehensive analysis of socio-economic aspects is considered indispensable to actually achieve sustainable designs as well as the study in detail of more complex systems in which products and services are combined. **Ceschin and Gaziulusoy** [2], carry out wide research about how design discipline is responding to sustainability questions and refer to different approaches focused on both the study combined of products and services and the encouragement

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https://doi.org/10.1016/j.heliyon.2023.e19866
Received 21 April 2023; Received in revised form 30 August 2023; Accepted 4 September 2023
Available online 7 September 2023

of new socio-technical systems, in which not only technical progress but also social and organisational innovations are developed.

The design of cultural services is also immersed in the application of sustainability approaches. Different efforts encouraged by a number of cultural organizations such as the **Tourism Industry Association of Canada** [3] or the International Council of Museums [4], have been made to adopt sustainable practices. It is noteworthy the initiative of The Museum of Fine Art in Boston, in which processes and materials used in the exhibition, transport and protection of permanent exhibited objects are reviewed and activities as lighting galleries, and heating and cooling systems, are also examined [5]. The study of impacts from an ecological point of view is mainly carried out in this pioneer research.

However, the study from a socio-economic perspective in which issues such as equity in hiring and working conditions, applying responsible procurement policies, strengthening local economies and building a strong community should be also addressed [6]. Thus, a sustainability concept with three dimensions should be considered. Environmental impacts (planet), economic aspects (profit), and social issues (people) should be simultaneously taken into account [7,8]. The application of this approach, denominated "Triple Bottom Line (TBL)" [9] in 1997, was supposed to provoke deeper reflection about capitalism and its future, but it's become a mere accounting tool and most companies understood the concept as a balancing act [10]. Nowadays is also a challenge for designers, who need to adapt many of the existing design tools based only on reducing environmental impacts. Sustainability has also become a crucial

Table 1
Studies applying sustainable design tools.

Authors - Product/Service analyzed -	Life cycle stages	Sustain. dimensions	Tools used in the study	Design objectives
Sustainable design of products				
Ciroth and Franze, 2011 [29] - Notebook for office use -	Entire life cycle	Env/ Social	Env. life cycle assessment, Social life cycle assessment	Detection and analysis of the main product impacts
Bereketli and Genevois, 2013 [30] - Hand blender -	Entire life cycle	Env	Integrated quality function deployment for environment	Identify product improvement strategies
Buchert et al., 2015 [31] - Bicycle frame -	Creation	Env/ Ec/Social	Life cycle sustain. assessment; Multi-criteria decision tree	Quantify inefficient design solutions
Asadi et al., 2016 [32] - Plumbing system -	Entire life cycle	Env/ Ec	Life cycle assessment; Life cycle costing	Study of two different design alternatives
Kim and Moon, 2017 [33] - Coffee makers -	Entire life cycle	Env/ Social	Sustainable platform for product family	Integrate sustain. and risk value in product family design
Vinodh et al., 2017 [34] - Consumer electronics -	Creation/ Use	Env	Fuzzy quality function deployment	Design prioritizing customer needs and sustainability issues
Badurdeen et al., 2018 [35] - Toner cartridges -	Entire life cycle	Env/Ec	Multi-lifecycle methodology; End-of-life strategies	Identify superior product configuration designs
Ferrari et al., 2019 [36] - Ceramic tiles -	Entire life cycle	Env/Ec/Social	Life cycle sustainability assessment	Benchmarking to decision makers, designers and users
Ocampo et al., 2020 [37] - Food products -	Creation	Env/Ec/Social	Quality function deployment; Analytic hierarchy process	Interdependencies among design decision parameters
Sustainable design of services				
Farreny et al., 2012 [38] - Museums -	Provision	Env	Statistical analysis; Emission factors	Evaluation of consumptions in cultural services
Amaya et al., 2014 [39] - Bicycle sharing -	Entire life cycle	Env	Life cycle analysis	Design for intensified use in product-service systems
Baden and Prasad 2016 [40] - Hairdressing -	Provision	Env	Surveys; Participants' motivation	Adopt more sustainable hair-care practices
Bartolozzi et al., 2018 [41] - Municipal street sweeping -	Provision	Env	Life cycle assessment; Product env. footprint	Comparative study of sweeping services
Álvarez-Rodríguez et al., 2019 [42] - Grocery store service -	Provision	Env	Data envelope analysis; Life cycle assessment	Performance analysis of 30 grocery stores
Arzoumanidis et al., 2019 [43] - Pollination service -	Creation, Provision	Env	Life cycle assessment; Sensitivity analysis	Identification of the most critical stage
Arias et al., 2020 [44] - Wastewater treatment service -	Provision	Env	Life cycle assess.; Sensitivity and uncertainty analysis	Propose a more sustainable system for new dwelling
Liu et al., 2020 [45] - Urban food delivery service -	Entire life cycle	Env	Life cycle assess.; Surveys; Kernel density analysis	Study of impacts in different companies
Hartono, 2020 [46] - Airport management service -	Provision	Env/Ec/Social	Ergonomics concepts; TRIZ methodology	Guideline to understand customer emotional needs
Sierra et al., 2021 [47] - Shared transport service -	Provision	Env	ECO-Service design	Ideation of new services with user experience requirements

factor in the creation process of cultural services and it is being integrated gradually in this practice.

Conventionally, a design process consists of a chain of tasks to solve a problem, in which evaluation and improvement procedures are included [11,12]. Authors have addressed sustainability in the design process implementing guides that mainly consist of various sustainability actions, which complement those conventional tasks developed along each design stage [13–16]. At the same time, a set of specific tools have been developed to carry out tasks such as to integrate sustainability requirements, achieve sustainability assessment or introduce improvement strategies [17–20]. These tools have been mainly applied to product systems taking into account a whole life cycle perspective, from raw material selection to end-of-life processes such as reuse, recycling and lastly disposal. As Table 1 shows, studies about sustainable design of products usually include the analysis of different sustainability dimensions along its entire life cycle. However, studies regarding the sustainability of service systems are much fewer and these are not carried out with a whole life cycle perspective and a TBL approach.

On the other hand, the development of more service-based systems is a trend in the current economy (service-based economy or servitization) due in part to the fact that services have a relevant role in fulfilling consumers' needs and generating value [21], and also because these systems apparently generate a lower demand for resources [22]. Product and service systems are different modes of delivering satisfaction and solving requirements of customers and users, but they are not independently developed in practice [23]. Services are based on the use of products and products require some support services, so both can be considered as parts of larger systems in which a set of links can be established [24]. On the other hand, a new way of interaction between companies and customers can be achieved from the combination of products and services with a business objective. The resulting systems, denominated Product-Service Systems (PSS) have been the object of a great attention in the last decade, since they theoretically represent a promising model to guide our production and consumption system towards sustainability [25,26]. A number of research works have been focused on the development of a practical PSS design methodology [27], although this research is still in an early stage. In this work, cultural services, which are supported by different product and service systems, are studied. The analysis of sustainability aspects in these systems where products and services are combined, individually for each involved system as well as for the global system, becomes critical to carry out design applying sustainable principles.

Cultural activities aim at providing a service to the society. In the case of cultural exhibitions, these are events organised from a wide number of institutions offering varied experiences for education, enjoyment, reflection and knowledge sharing [28]. At the same time, a set of physical artifacts or installations and a number of associated services such as insurance, shipping, storage, conservation or mounting, are part of these complex systems. In addition, different types of cultural exhibitions can be differentiated: indoor and outdoor; permanent, temporal and itinerant. Thus, the design of cultural exhibitions with sustainable criteria is a challenge for designers, who need approaches, models and tools to develop their work. In order to facilitate this process this paper proposes a set of suitable actions and approaches, pointing out limitations and knowledge gaps; then presents two different cases of study aimed at implementing these approaches in the design of cultural exhibitions; and finishes by the discussion of the results obtained and identification of some key areas for future research.

2. Methods

In order to achieve sustainable designs, the classic structure of four phases applied in a design process [11], can be complemented with the development of different sustainability actions. In phase 1 - strategic definition, the inclusion of a sustainability strategy is proposed to complement the definition of design objectives. In phase 2 - conceptual design, a number of sustainability approaches,

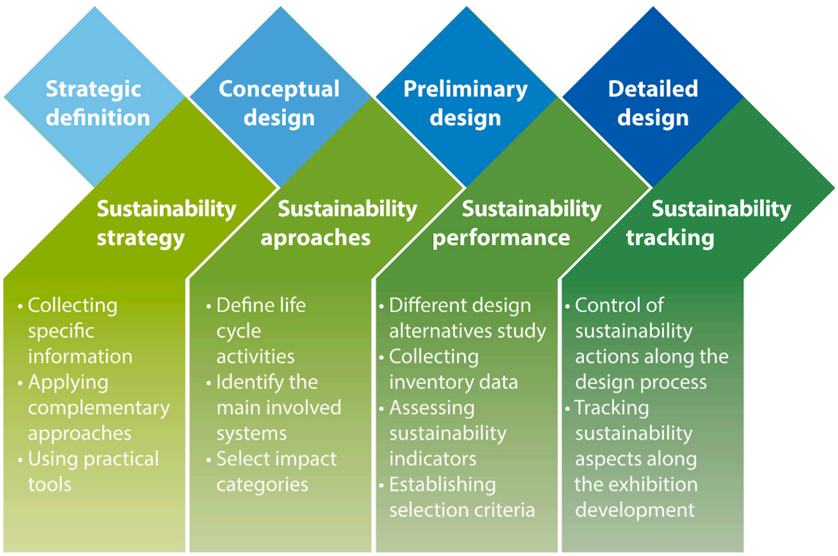


Fig. 1. Sustainability actions along the design process.

which allow achieving the sustainability objectives previously established, are put forward. In phase 3 - preliminary design, the sustainability performance of those alternatives generated to solve the design problem, is analyzed and selection criteria are applied. Finally, in phase 4 - detailed design, the verification of sustainability data and minimum sustainable requirements achieved, should be carried out to achieve an optimal design. Sustainability actions are shown in Fig. 1 and are examined in detail coming up next.

1) Sustainability strategy

Sustainability is understood in this work as the integration of aspects associated with economic viability, environmental impact, and social equity. Thus, sustainability strategy should be based on collecting specific information associated with each dimension. At the same time, a number of sustainability indicators should be included along with other service operating parameters in the decision-making process of the final design.

The development of cultural exhibitions entails a wide number of activities, is supported by numerous systems (products and services) and different stakeholders can be involved. In order to address this complexity, sustainability strategy must be based on the application of complementary approaches that allow the designer to identify the most significant systems, activities, and stakeholders concerned regarding both ecological and socio-economic issues. Three main approaches, which will be examined below, will be applied in this work. On the other hand, the sustainability performance of different design alternatives and the subsequent sustainability-oriented decision-making only can be carried out through the use of practical sustainability assessment tools, which allow designers to easily integrate sustainability data and interpret the results obtained.

2) Sustainability approaches

The following approaches are proposed to be simultaneously applied.

a) Life cycle approach

Many authors make emphasis on a design process thinking in the life cycle of the system to be designed and a wide number of works show that if design methods fail to include a life cycle perspective, resulting design decisions are biassed or are not optimum [35],[48],[49].

Thus, the designer should apply a life cycle perspective. Firstly, it should be noted that three main stages named creation, provision, and end-of-life, can be differentiated in the development of any service. According to this simplified description, all activities along the life cycle can be grouped into activities developed prior to the service provision, activities associated with the provision, and activities carried out after the provision [50]. In a lot of cases, the provision stage is the only one considered in studies associated with the sustainability of service systems. Activities in this stage aim at satisfying the customer demands by the service provider. However, a life cycle perspective means taking into account those activities carried out in the creation stage to develop the service provision under optimal conditions as well as the activities performed in the end-of-life stage to satisfactorily treat all materials used along the service provision.

A cultural exhibition entails the development of a number of activities, which begin with the ideation and selection of both exhibition space and contents to exhibit and finish archiving those contents and processing the waste generated. Other activities such as the transport of materials and artifacts along the exhibition development, the attention to visitors during the event, or the exhibition disassembly when it is finished must be also considered. The main activities involved in the life cycle and those specific workers concerned in each activity are indicated in Fig. 2. More detailed description of activities or their breakdown into more explicit tasks can be made according to the exhibition characteristics.

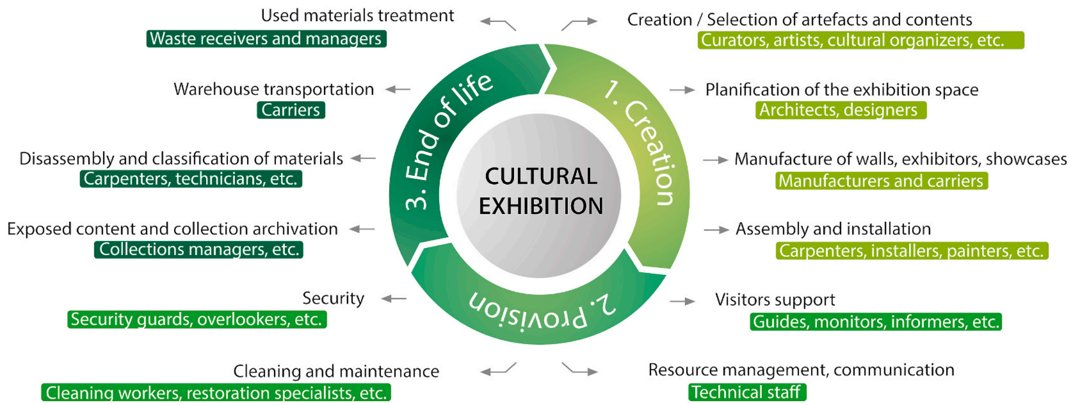


Fig. 2. Main activities involved in the life cycle of a cultural exhibition.

b) Flows between systems approach

This approach considers that any type of system is composed of interconnected product and service systems between which a flow of activities occurs. In addition, one foreground system (FS) can be identified as the main or "core" system and different background systems (BS) or systems that support FS along its life cycle can be recognized as "satellite" systems [24],[50].

This approach can be used to identify the systems implicated in the design process of a cultural exhibition and to determine how the sustainable design of FS can be affected by different BSs. A graphic representation of this approach is shown in Fig. 3. The system designated as FS is the cultural exhibition and the systems designated as BSs are different product and service systems that are involved in the FS development. The conservation of exhibited contents, the transport of materials, or the disassembly of the exhibition space, are service systems designated, respectively, BS_1, BS_3, and BS_5. The artifacts and objects exhibited or the materials used on the exhibition space layout are product systems designated, respectively, BS_2 and BS_4. Other systems (denominated BS_n) could be also considered.

The FS development is affected by a considerable number of BSs, so determining which the most influential systems are or which stay out of our study is an important task in the design process. At the same time, the stages of creation, use/provision and end-of-life can be distinguished in each product/service system, which can be totally or partially considered according to the system implication and the depth of the study carried out. A greater number of activities along the life cycle should be considered in those BSs which significantly affect FS. In addition, connections between different BSs can be analyzed as well as the integration of some of them or their breakdown into more explicit systems according to the problem object of study. In this work, the study will be limited to the most significant BSs affecting the cultural exhibition development.

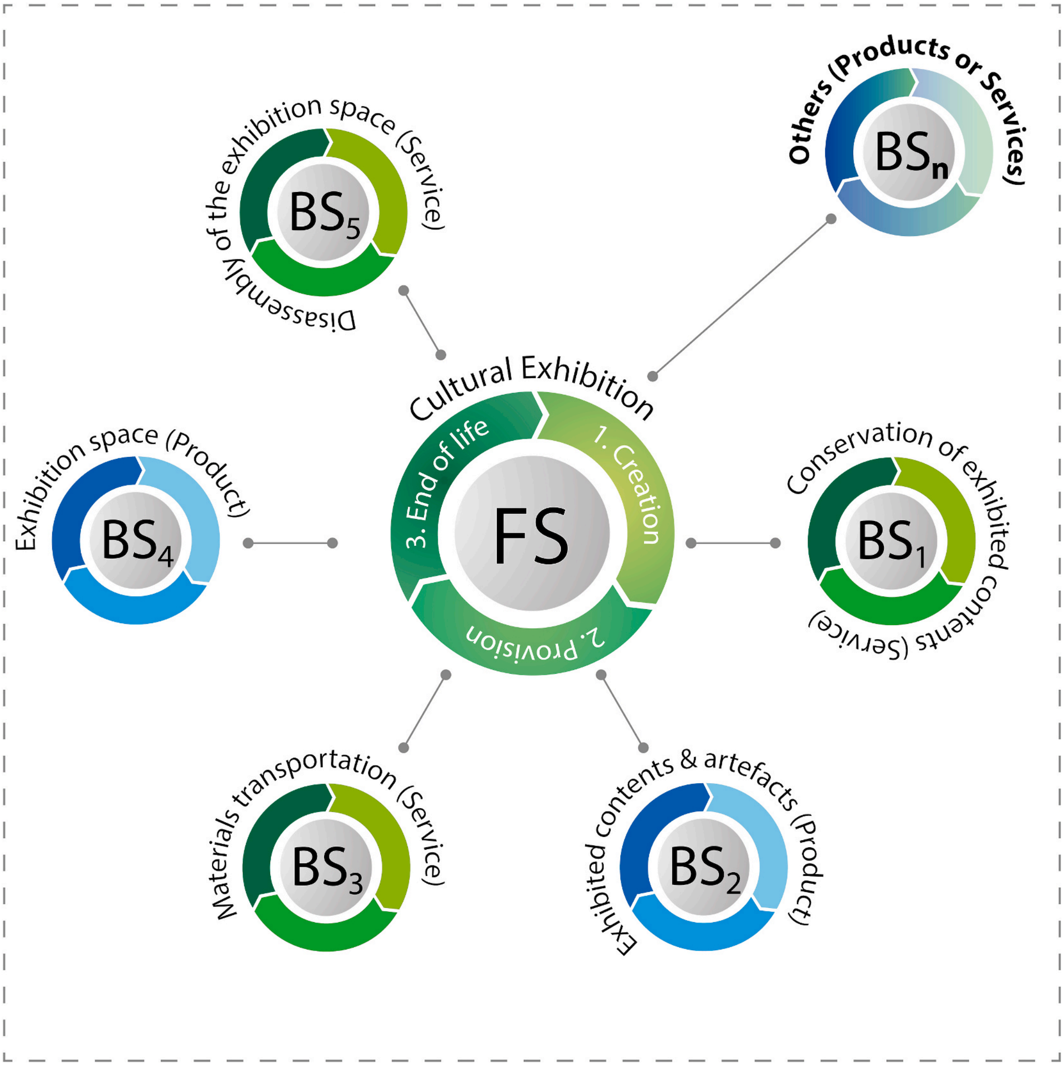


Fig. 3. Flows between systems approach.

c) Triple bottom line approach

According to this approach, sustainability is based on the study of three dimensions: environmental, economic and social [9]. This represents a significant change with respect to the concept of sustainability based only on the study of environmental issues. In the broadest sense, environmental sustainability involves the entire global ecosystem (oceans, atmosphere and land) and to address this complexity, a number of categories and subcategories of impact can be identified. In the ReCiPe methodology [51,52], human health, ecosystem quality and resource scarcity are selected as the three main categories of environmental protection. Economic issues are usually valued by considering costs of different activities along the life cycle although other economic aspects such as the financial results from activities can be also used [53]. On the other hand, a sustainable society is one in which all members have equal rights and all share equitably in societal benefits. The analysis of social aspects is based on six different stakeholder categories (workers, consumers, local community, society, value chain actors and children) according to the UNEP's guidelines [54]. In line with these works, the most significant impact categories and subcategories established for each sustainability dimension are shown in Fig. 4.

Depending on the context and the scope of the study, a number of categories, which represent the most relevant information should be selected by the designer. In this work, the damage to ecosystems, the financial results and the workers are, respectively, the categories selected in the environmental, economic and social dimensions.

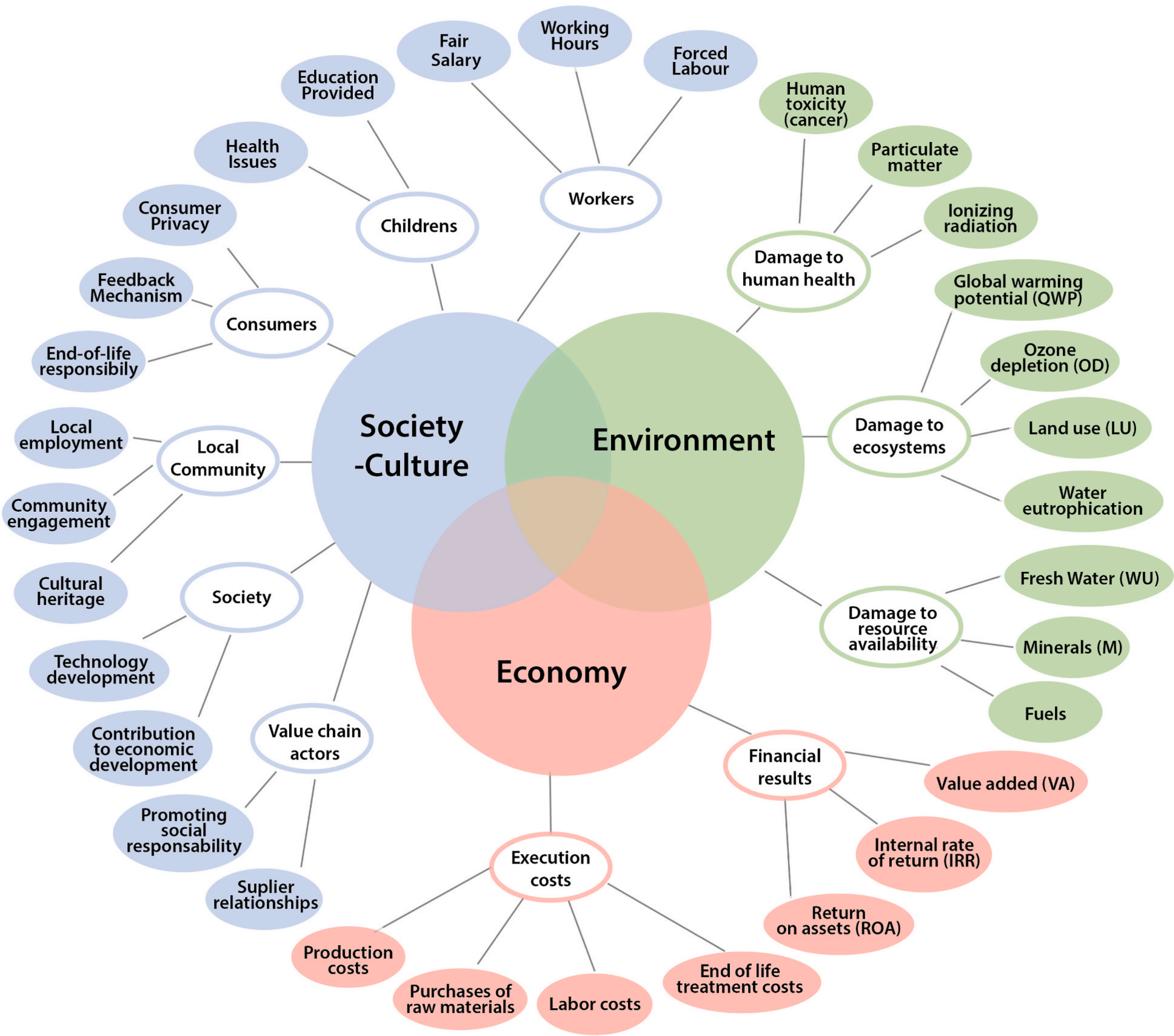


Fig. 4. Impact categories and subcategories for each sustainability dimension.

3) Sustainability performance

Evaluating the sustainability performance of different design alternatives is possible if appropriate tools are used. The Life Cycle Sustainability Assessment (LCSA) framework [55] is considered a pragmatic method to evaluate the sustainability of a product/service system. It is based on three techniques: environmental life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA). A set of principles have been recently established for harmonizing the practical application of LCSA, but also to facilitate its interpretation and increase its usefulness for non-experts and decision-makers [56]. LCSA application requires the selection of a number of indicators associated with the categories and subcategories of impact defined in each sustainability dimension.

In order to quantitatively value the impact of those activities involved in the development of cultural exhibitions the following indicators are selected in this work. The global warming potential (GWP) indicator, which represents total emissions of greenhouse gases, is used to value the environmental impact. Economic feasibility is determined through both the execution costs (Ce) and the value added (VA) that expresses the net operating profit of the cultural service. In addition, social impact is valued by the working time (T_w) or time required by the workers to carry out an activity. More details about the definition, calculation and application of these indicators can be consulted in Table 2 and revised in **Santolaya et al. (2019)** [20].

Sustainability indicators can be obtained if a detailed inventory is carried out for those activities involved in the development of the cultural exhibition. In addition, the use of databases and specific software is required to make the calculation for each design alternative. Database as GaBi ts 9.2 software [57] and ProBas (v.1.5.5) database [58] are used in this work to obtain environmental indicators of different materials and products; working times and workers' salaries were valued along the lines of the International Trade Union Confederation [60]**.** Greenhouse gas emissions due to both electric and fuel consumptions were evaluated using the emission factors provided by electric commercial companies [59].

On the other hand, applying criteria to reflect the importance of each sustainability dimension and thus, assigning different weights to indicators will be determinant to compare design alternatives. These criteria can considerably change for each system object of study, according to the interests and preferences of the decision-makers. Finally, an aggregated index representing the global sustainability of each alternative could be obtained to facilitate the comparison process.

Table 2
Sustainability indicators used in this work.

Environmental dimension		
Global Warming Potential (GWP)	Category: Damage to ecosystems	Units: (Kg CO2-eq)
Interpretation: It represents the total emissions of the greenhouse gases computing the radiative forcing over a time horizon (usually, one hundred years). **Selection:** It is essential environmental information and the most used indicator in sustainability studies.	**Calculation:** It is generally calculated using the corresponding unit indicator, which is obtained from different databases. In the case of raw materials and other products, unit indicator is expressed as emissions per mass unit. Data representing average production and supply conditions for a variety of products are used in databases of specific software such as GaBi or SimaPro.	
Economic dimension		
Value added (VA)	Category: Financial results	Units: (€)
Interpretation: It represents the net operating profit obtained from the development of an economic activity. **Selection:** It is a practical indicator to show the economic viability of any activity. In this case, the activity carried out is the provision of the cultural service.	**Calculation:** It is obtained as the difference between revenues and costs. Revenues depend on the price of the service and costs are usually calculated using the following cost groups: raw materials, energy consumption, labour, consumables, indirect costs, amortisation, … Different products and services price tables as well as salaries tables are used to value the production costs.	
Social dimension		
Working time (T_W)	Category: workers	Units: (h)
Interpretation: Time developing an activity. It can be defined including all workers or individually. **Selection:** Workers category is very relevant to know the social impact of the service provided and it is a quantitative indicator that can be easily compared.	**Calculation:** In this work, the total working time or accumulated working time is obtained as the sum of working hours of all workers involved in the development of the service. Temporary planning of tasks and workers required is carried out using Gantt diagrams and specific tools of project planning.	

Sustainability assessment carried out in three dimensions and throughout the entire life cycle implies a wide scope of study. Hence, the number of indicators used for each dimension has to be limited. The assessment of the sustainability performance requires access to specialized databases. Those databases reveal some limitations, especially with regard to the end-of-life cycle stage of products and services. Those limitations will be gradually overcome with the development of the databases.

4) Sustainability tracking

Sustainability tracking is mainly based on the control of those sustainability actions carried out along the design process. A list of the most significant aspects to check and the minimum requirements to be achieved are shown in Table 3. Actions enumerated are a set of logical steps to carry out along the sustainable design of a cultural service. Each action is identified with both a number and a letter. The number indicates the phase of the design process in which should be performed according to those four phases previously defined and the letter indicates the execution order. For example, *(Act 2.b)* expresses the action carried out within the Phase 2. Application of sustainability approaches, and is referred to the identification of critical systems in the cultural service object of study. A set of sustainability actions that begin identifying the type and characteristics of the cultural service object of design *(Act 1.a)* and finish comparing data between initial design service and results obtained when it is developed *(Act 4.e)* are established. This list of actions, which are expressed in a generic form to allow us its application in different contexts, is also regarded as a set of aspects to check in the design process. The appropriate tools, which are recommended to track the development of each action, are also indicated in Table 3. We can observe that multiple tools (techniques, documents, tables, guidelines, …) should be used to carry out a sustainable design. In particular, the elaboration of a sustainability report/memory is proposed in order to keep record of all sustainability aspects considered in the design process.

In the following section, sustainability is integrated in the design process of two cultural services. The sequence of actions carried

Table 3
Checking sustainability actions.

Aspect to check	Minimum requirements	Tools used	✓
1. Sustainability strategy definition			
(Act 1.a) Cultural service features	Exhibition type and main features are defined	Design brief	
(Act 1.b) Sustainability objectives	Sustainability concept is integrated in the project and a set of objectives are established	Sustainability report/memory	
2. Application of sustainability approaches			
(Act 2.a) Design requirements	Sustainability approaches are applied in compliance with design specifications	Integrating requirements tools	
(Act 2.b) Critical systems	Different systems (FS and BSs) are recognized and critical systems are established	Conceptual graphics	
(Act 2.d) Design alternatives	Sustainability approaches are released in two design alternatives	Creativity techniques	
(Act 2.c) Life cycle activities	Life-cycle perspective is applied. The main stages and activities are identified	Life-cycle thinking tools	
(Act 2.e) Sustainability dimensions	Categories and subcategories of impact are selected for each sustainability dimension	Sustainability criteria	
3. Sustainability analysis of design alternatives			
(Act 3.a) Inventory data	Specific data of activities involved in the exhibition development are gathered	Inventory tables	
(Act 3.b) Sustainability indicators	Leastwise one indicator is obtained for each category and sustainability dimension	LCSA/Database	
(Act 3.c) Analysis of alternatives	Indicators are compared in two (or more) design alternatives	Comparative tables and diagrams	
(Act 3.d) Selection criteria	Selection criteria are established. The most sustainable alternative is chosen	Decision making techniques and tools	
(Act 3.e) Design refinement	Design improvements in line with the sustainability strategy are recommended	Sustainability guidelines	
4. Sustainability tracking in the exhibition development			
(Act 4.a) Social responsibility	Companies and entities involved in the exhibition development promotes social responsibility	Official recognitions	
(Act 4.b) Execution times	Communication is fluid between value chain actors. Works and payment are carry out on time	Time diagrams	
(Act 4.c) Cultural organisation	Presence of partnership regarding research and development. Efforts in eco-friendliness technology	Social engagement in sustainability report	
(Act 4.d) Visitors satisfaction	Different feedback mechanisms and practices are used to know customer satisfaction	Surveys/Interviews	
(Act 4.e) Sustainability data	Data are recorded along the exhibition life cycle and compared with estimated data in design	Inventory tables	

out in each case is efficiently indicated using the code of each sustainability action and, at the same time, this code checks the integration of each action in the design process. Additionally, a number of aspects are recommended to track when the exhibition is developing. These are also indicated in this checklist. Thus, the designer can verify if sustainability data estimated along the design process match the final data obtained in the implementation of activities and can also obtain relevant information to improve the design of future exhibitions. In particular, checking social engagement with stakeholders (visitors, companies, cultural organizations, …) is proposed as the application of feedback mechanisms in the consumers' category and the presence of partnerships regarding research and technology development in the stakeholders' group society.

3. Case studies

Two different cultural exhibitions are studied. Firstly, the design of an itinerary exhibition, which travels to different European destinations and requires a wide room for the presentation of artifacts and other contents, is conducted. Secondly, the design of an outdoor exhibition that is developed in the streets of a big city using a number of counterweight exhibitors, is carried out. Sustainability is integrated into the design process by applying the methodological framework previously exposed and pointing out each of the tasks developed, from *(Act 1.a)* to *(Act 3.e)*, which were enumerated in Table 3.

3.1. Case 1 - indoor exhibition

A big number of cultural exhibitions are developed in sheltered indoor spaces to guarantee the safety of the exhibited contents. In this case, a company that creates meaningful touring exhibitions is commissioned to design an educative exhibition about historical events. After its inauguration, it will travel to eight different European cities, staying for six months in each of them *(Act 1.a)*. Sustainability is integrated in the design process with the final objective of selecting the most sustainable alternative fulfilling design requirements *(Act 1.b)*.

In this case, the exhibited contents are selected by the curators of the cultural exhibition, so the design team has mainly the mission of conceiving the most suitable showroom to display those contents. Particularly, a wide enclosed room keeping specific aesthetics and careful attention to visitors is required. Thus, the exhibition space layout and the transport of materials between destinations are considered critical systems in the exhibition design. Other systems as the historical contents exhibited (artifacts, reproductions, facsimiles, models, etc.) as well as showcases, wall-cases and frameworks used as protection are here not considered. Nevertheless, based on the typology and characteristics of the contents that will be displayed, a total area of approximately 2500 m^2 will be required in the cultural exhibition development and three trucks will be needed to transport a total weight of 19600 Kg (fly cases with collections and display furniture) *(Act 2.a)*.

In each destination, a wide diaphanous area should be transformed into a set of connected rooms, in which a series of selected contents will be sequentially displayed. With this objective as well as to provide a sensation of continuity and comfort, the use of a modular walls system and widespread moquette is proposed. The exhibition space layout is the background system designated BS_1 in Fig. 5. In addition, BS_2 is the transport service between destinations that includes the transport of artifacts as well as those materials used in the exhibition space layout *(Act 2.b)*.

The development of the cultural exhibition taking into account a life cycle perspective involves the study of activities throughout the creation, provision, and end-of-life stages. In the creation stage, projecting the exhibition space as well as the manufacturing process and assembly on site of the modular wall system should be considered. The service provision entails a number of activities associated with the visitors' attention (ticketing, gift shop, cloakroom, and guided cultural tours) as well as coordination, security, and cleaning activities. After the exhibition is over, dismantling activities are carried out. Exhibition content is organized to transport it to the next destination. Materials, which cannot be reused are classified into appropriate categories and transported to recycling and waste management plants *(Act 2.c)*.

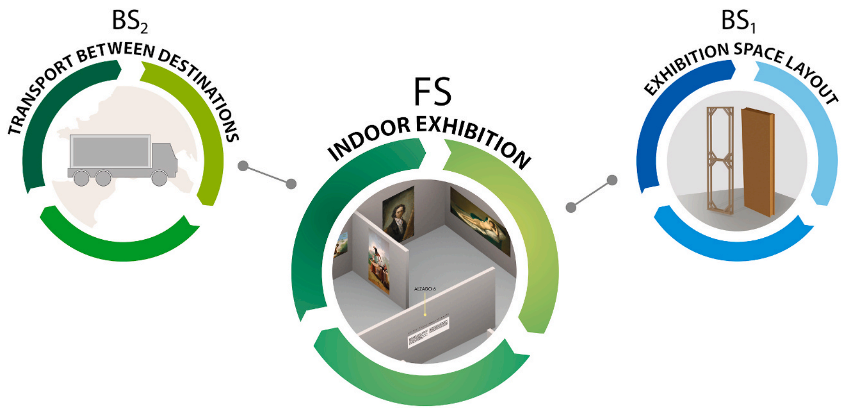


Fig. 5. Case 1: Indoor exhibition. Main systems involved in the design process.

Two design alternatives focused on the planification of the exhibition space are considered. Taking into account that a modular wall system is proposed to transform the total showroom area, alternative 1 is based on the use of wooden components while the use of anodized aluminum is preferred in alternative 2. More details of each option *(Act 2.d)* are indicated in Table 4.

The selection of the most sustainable alternative using categories of three different sustainability dimensions *(Act 2.e)*, involves the compilation and study of a wide number of data associated with the exhibition development. Life cycle activities associated with each critical system of the two alternatives are considered. Data on working times, energy consumption, and costs estimated for the full development of the itinerary exhibition in eight different destinations are summarised in Table 5 *(Act 3.a)*.

Data of different activities carried out in the creation and end-of-life stages are calculated taking into account that around 400 modules of 1x3x0.2 m each, should be used in the total exhibition area. Higher energy consumption, working times, and labour costs are noted in alternative 1. The use of polyester for the moquette and the application of paint in finishing operations cause a significant increase of the energy consumed in materials creation processes. In addition, the manufacturing and assembly (painting is included) of each module based on the use of wooden components entails intense labour. In the service provision stage, a suitable number of shifts and employees were considered in different activities. Energy consumption is mainly caused by the lighting and air-conditioning of the exhibition hall as well as the loading of audio-guides. The exhibition is open every day for 11 h, a total number of 300000 visits were estimated in each destination and it is considered that 70% of visitors make use of an audio guide system. No differences are noted in the data estimated for each design alternative along the provision stage.

In the end-of-life stage, the costs of disassembly, transport to the recycling plants and waste deposition activities are assessed according to the volume of material handled. Waste separation, in line with the existing regulations, and waste transport to the recycling facilities, assuming a distance of 5–10 km from the worksite, was considered. In alternative 2, the modular wall system could be reused in the following destinations. Only the moquette and textile panels, in which text should be written in different languages, are newly manufactured. Materials should be transported between destinations along with the rest of the artifacts and exhibited contents. A total of 24600 Kg will be carried in two trucks an average distance of 580 Km between European cities that host the exhibition. Thus, higher energy consumption and costs are estimated.

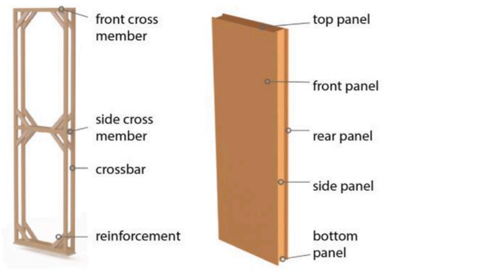
Sustainability indicators were calculated for each design alternative *(Act 3.b)*. Results obtained, expressed per every 1000 visitors to the cultural exhibition, are presented in Table 6. The greenhouse gas emissions (environmental dimension) due to the materials and energy consumptions were valued using a specific database previously indicated in the methods section. The added value indicator (economic dimension) was obtained estimating an average ticket price of 8€. The accumulated working times by those workers involved in the different activities of the service development were also determined (social dimension). Data are expressed globally and separately for each system initially identified.

If indicators of the global system are examined, we observe that alternative 2 is more sustainable than alternative 1 *(Act 3.c)*, since lower greenhouse gas emissions are obtained (environmental dimension), the value-added increases due to the costs reduction (economic dimension) and the accumulated working time along different activities reduces (social dimension). A comparative review of the indicators obtained for each system allows us to observe that the impacts of alternative 2 are higher than those of alternative 1

Table 4
Case 1: Indoor exhibition. Design alternatives.

Alternative 1

The wall's structure is constructed using wooden slats fixed with dowels and adhesives.
Medium-density fiberboard (MDF) panels cover this structure, which are plastered and painted. The total weight of each module is 106.1 Kg (1x3x0.2 m).
Printed and cut-out vinyl could be then attached.
A polyamide moquette thickness 6 mm and weight 4.3 kg/m^2, is used to protect the floor during the assembly and painting operations. The moquette should include a plastic protector, which will be retired before the inauguration.



Alternative 2

The wall's structure is composed of standard anodized aluminium profiles, which are fixed with quick joints. Later a panel made of printed polyester fabric is attached to the supporting structure on both sides with a silicone guide on its perimeter. Each module weighs 61.5 Kg (1x3x0.2 m).
Since in this case, there is no risk of damage during assembly and painting processes, a 3 mm thick polyester carpet without a protector is used to fill the technical floor. This carpet is fixed with flooring adhesive.

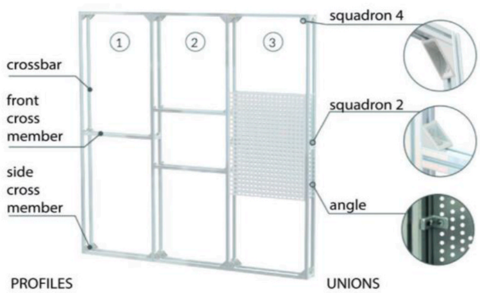


Table 5
Case 1: Indoor exhibition. Data estimated for each design alternative.

		Working time ($h\cdot10^3$)		Labour costs (€$\cdot10^3$)		Energy (Kw·h $\cdot10^3$)		Material + Energy Costs (€$\cdot10^3$)	
		Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2
Creation stage									
BS_1	Planning	3.5	4.1	152	176	11.6	13.5	1.4	1.6
	Manufacturing	3.2	0.11	56	8.8	2777	306	1022	336
	Transp + Assem	10.8	2.8	190	55	18.4	16.8	4.3	9.6
Provision stage									
FS	Coordination	2.16 (2 empl.)		43.5 (2 empl.)		230 (air-cond.)		27.3 (air-cond.)	
	Attention	17.8 (18 empl.)		148.7 (18 empl.)		0.15 (vacuuming)		0.018 (vacuuming)	
	Cleaning	1.6 (3 empl.)		16.9 (3 empl.)		0.71 (audio-guide)		0.085(audio-guide)	
	Security	12.9 (9 empl.)		117.4 (9 empl.)		76 (lighting)		9.1 (lighting)	
End-of-life stage									
BS_1	Disass + Transp	1.2	0.75	65	46.5	11.2	4.8	12.8	1.6
BS_2	Treat/Depos	–	–	–	–	0.02	2.3	12	0.1
	Transp - Destin.	0.68	1.1	11.2	19.2	50.4	168	26.4	44

Table 6
Case 1: Indoor exhibition. Sustainability indicators for each design alternative.

	Environmental dimension GWP (Kg CO_2-eq)		Economic dimension VA (€)		Social dimension T_W (h)	
	Alt 1	**Alt 2**	**Alt 1**	**Alt 2**	**Alt 1**	**Alt 2**
(BS_1) Space layout	379	39	38	17	9	4
(BS_2) Transport service	9	15	0.6	1	0.2	0.4
(FS) Provision stage	220	220	5580	5912	115	115
Global system	**608**	**274**	**5618**	**5930**	**124,2**	**119,4**

**Data expressed for every 1000 visitors to the cultural exhibition*

for BS_2 (transport service), but considerably lower for BS_1 (space layout). Thus, alternative 2, which shows better indicators due to the reuse of components, is selected as the final design option for the exhibition development *(Act 3.d)*. It should be noted that criteria to reflect the importance of each sustainability dimension are not applied in this case.

Sustainability actuations are also being tracked along the exhibition development. In particular, cultural organization efforts associated with the use of sustainable technology in the exhibition of the content have been pointed out. A new research project in which the impact of new media as virtual environments and augmented reality is analyzed has been requested *(Act 4.c)*. Additionally, mechanisms to know visitors' satisfaction have been introduced. A survey to obtain information about the cultural impact expressed by

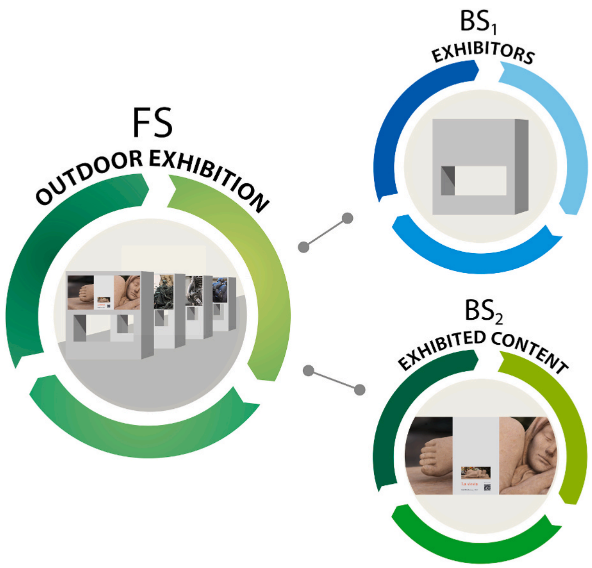


Fig. 6. Case 2: Outdoor exhibition. Main systems involved in the design process.

the visitors as well as proposals to improve the exhibition's sustainability has been designed *(Act 4.d)*.

3.2. Case 2 - outdoor exhibition

Outdoor exhibitions are usually organized by municipalities, cultural institutions, or artistic collectives with the objective to favour access to culture for all audiences as well as to promote knowledge and reflection on current social issues. In this case, the design of an open-air exhibition, in which up to thirty different socio-cultural topics are addressed over a total period of five years, is carried out. The project is developed in a big city of Spain where a number of appropriate locations are selected to exhibit those topics staying for one month in each of them *(Act 1.a)*.

The sustainability objective is focused on selecting the most sustainable design alternative fulfilling those requirements pointed out by the organizer which, in this case, is the City Council *(Act 1.b)*. In particular, the design of a set of resistant exhibitors, which can be easily installed in different public places of the city without blocking people's transit, and the design of contents associated with the cultural experience, which can be displayed on good-visibility areas of the supports, should be considered *(Act 2.a)*. Thus, the main background systems involved in the development of this cultural service are both exhibitors and exhibited contents, which are designated, respectively, BS_1 and BS_2 (Fig. 6). Other systems such as the exhibition space layout or the conservation of exhibited contents are here not taken into account *(Act 2.b)*.

Three types of supports are usually used in open-air exhibitions: supports fixed to the ground, supports that guarantee stability by their geometry and supports with counterweight. Although the first one can represent space for temporary exhibition, its fixture to the ground converts those elements into permanent city furniture. The second one requires larger space and can be exposed only in locations that have no strong winds, which makes the third one the most popular and versatile type and is chosen in this case. On the other hand, the use of replaceable materials including different graphic reproductions is the method selected to create the cultural content. This allows keeping the same support design for all topics addressed during the exhibition. Moreover, in order to achieve a balance between the space occupied by the exhibition and the amount of content displayed, a total number of ten free-standing exhibitors are proposed.

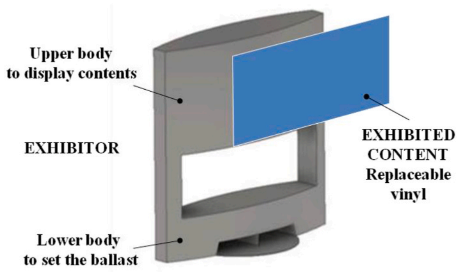
Two design alternatives, which mainly differ in the use of self-lighting of contents, are proposed. In both cases, counterweight exhibitors and divided into two main parts are considered. The upper part, located at eye level, provides a wide surface on which the content is displayed. The lower part, which houses the ballast that protects the exhibitor from unwanted displacement, guarantees stability and prevents vandalism. The area planned to display content is 2.1×1m in both cases and a total of 20 panels (using both sides of each support) are required. More details of each option *(Act 2.c)* are indicated in Table 7.

Applying a life cycle approach involves that a number of activities are examined along each stage of the cultural exhibition development *(Act 2.d)*. Service creation activities include concept generation of both exhibitors and exhibited contents, their manufacture and transport to the exhibition area, and their adequate distribution by a forklift operator. In the provision stage, activities such as cleaning and maintenance of the exhibition as well as the replacement of the material due to deterioration or vandalism

Table 7
Case 2: Outdoor exhibition. Design alternatives.

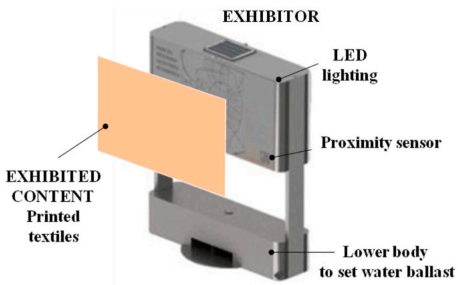
Alternative 1

Supports consist mainly of two elliptical bodies with 1 m and 0.45m-high whose casings are built in 2 mm stainless. The lower body is filled up with concrete, which acts as a ballast. Exhibitor is mounted on a base of 1.1 m diameter. Two openings at the bottom allow a forklift to move it. Printing content is adhered to the upper part using replaceable vinyl.
Each of the 30 exhibitions requires the printing of 20 vinyl panels (42 m^2) and its placement on both sides of each exhibitor.



Alternative 2

The use of LED lighting and a proximity sensor allows making this exhibition service accessible at night. A number of electronic components are included in the exhibitor design.
Exhibited contents are displayed on replaceable printed textiles. Each of the 30 exhibitions requires settling 45 m^2 of fabric.
Supports are made up of two prismatic parts and mounted on a round base. The material used for ballast is water. In each exhibition place, the exhibitor is filled and emptied. This facilitates the transport and the installation on site.



are considered. The end-of-life stage includes those activities needed for the dismantling, treatment, and final disposal of materials once the cultural service is over.

The selection of the most sustainable design alternative is based on the evaluation of indicators for each sustainability dimension *(Act 2.e)*. Thus, the estimation and study of a wide number of data associated with the exhibition development are carried out. In particular, data on working times, energy consumption, and costs are estimated for the full development of the 30 topics considered in the project. These are summarised in Table 8 *(Act 3.a)*. Life cycle activities associated with the BS_1 and BS_2 systems are considered in each design alternative.

In alternative 2, we can observe that estimated data of working time, energy consumption and costs in the manufacturing process of the supports are lower than alternative 1, due mainly to less amount of materials and painting is required. However, the manufacturing of contents using fabrics (alternative 2) entails an energy consumption considerably higher than using vinyl (alternative 1). In each case, the exhibited contents are renewed after each exhibition. The vinyl in alternative 1 and textiles in alternative 2. Exhibitors should be transported from each exhibition point in the city an average distance of 3.5 Km to the municipality workshops area, in which they are stockpiled for one month to the following exhibition. In assembly activities, the working times and labour costs estimated for alternative 2 are significantly higher.

Along the service provision stage, it is considered that the guided visit service is provided by two workers that perform three guided visits aimed at the child audience from Monday to Friday and two guided visits aimed at the general public during weekends. Moreover, cleaning and maintenance activities are taken into account, which includes the replacement of damaged contents and equipment deterioration. In alternative 2, the replacement of materials is more expensive due to the use of textiles and the additional energy consumption is also considered due to the use of lighting.

When the exhibition finishes after one month, those discarded contents are transported to a waste management plant. When the last exhibition is performed, after five years of use, the useful life of the supports finishes and the waste is sorted in categories and is transported to a recycling facility and a waste treatment plant located on the outskirts of the city. Metrics estimated in alternative 1 are higher than alternative 2, since more material has to be processed.

Sustainability indicators of the whole exhibition development were calculated for each design alternative *(Act 3.b)*. Results obtained are presented in Table 9. In this case, the execution costs indicator is selected in the economic dimension, since a net operating profit is not directly expected from the exhibition development. In addition, the greenhouse gas emissions and the accumulated working times by those workers involved in the different activities of the service development were, respectively, determined in the environmental and social dimensions. Data are expressed globally and separately for each system initially identified.

If indicators obtained for each system are compared, we observe that for BS_1 (exhibitor) impacts of alternative 2 are lower than those of alternative 1, but are higher for BS_2 (exhibited content). It is also noted that the second alternative involves higher environmental and economic impacts in the provision stage. Globally, alternative 2 presents lower emissions and working times but higher execution costs than alternative 1. Therefore, sustainability performance is better for the environmental and social dimensions but is worse for the economic dimension. In order to obtain a global sustainability evaluation, an aggregated index is calculated *(Act 3.c)*. The final design alternative selection will depend on weights proposed to each sustainability dimension. Four cases are considered: case 1, in which equal importance is given to each sustainability dimension and an equal weight of 0.33 is given to each of the three indicators; cases 2–4, in which a weight of 0.5 is assigned to a one dominant dimension and equal weight of 0.25 is assigned to the rest. Table 9 summarises the results obtained in each case.

For each sustainability indicator, the percentage variation between alternatives is first shown. Negative values indicate improvement whereas positive values indicate worsening. An aggregated index that represents the relative sustainability improvement between design alternatives is calculated in each case with the weights assigned to each indicator. We observe that cases 1, 2 and 4, in which equal importance and dominant environmental and social dimensions are, respectively, considered, result in selecting the

Table 8
Case 2: Outdoor exhibition. Data estimated for each design alternative.

		Working time ($h \cdot 10^3$)		Labour costs ($€ \cdot 10^3$)		Energy ($Kw \cdot h \cdot 10^3$)		Material + Energy Costs ($€ \cdot 10^3$)	
		Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2	Alt 1	Alt 2
Creation stage									
BS_1	Ideation	0.28	0.3	12	12.6	0.9	1	0.1	0.12
BS_2		2.4	2.4	103	103	8	8	0.9	0.9
BS_1	Manufacturing	0.2	0.1	1.9	0.45	42.7	27.4	10.4	8.1
BS_2		1.8	1.2	13.3	8.8	0.6	4.7	52.9	98.6
BS_1+ BS_2	Transp + Assem	0.15	0.33	2.4	3.7	5.2	6.1	11.6	11.1
Provision stage									
FS	Cleaning	0.48	0.24	8.7	4.3	(replac.)	(replac.)	(replac.)	(replac.)
	Maintenance	0.18	0.13	2.8	2	0.05	0.4	1.2	3.5
	Guided visits	2.28	2.28	41.3	41.3		(light.) 0.27		(light.) 0.03
End-of-life stage									
BS_1	Disass + Transp + Treat/Depos	0.16	0.09	2.6	1.4	6.7	5.4	12.8	9
BS_2		0.2	0.2	1.6	1.6				

Table 9
Case 2: Outdoor exhibition. Sustainability indicators for each design alternative.

	Environmental dimension GWP (Kg CO_2-eq $\cdot 10^3$)		Economic dimension Ce (€ $\cdot 10^3$)		Social dimension T_W (h $\cdot 10^3$)		
	Alt 1	**Alt 2**	**Alt 1**	**Alt 2**	**Alt 1**	**Alt 2**	
(BS_1) Exhibitors	14	9.6	40.4	34.6	0.7	0.65	
(BS_2) Exhibited content	4.1	5.1	185.1	210	4.4	3.9	
(FS) Provision stage	0.09	1.1	54	81	2.9	2.6	
Global system	**18.2**	**15.8**	**279.5**	**325.6**	**8**	**7.15**	
							Aggreg. index
Indicators variation (%)		−13.1		+16.5		−10.6	
Case 1	0.33		0.33		0.33		**−2.37**
Case 2	0.5		0.25		0.25		**−5.08**
Case 3	0.25		0.5		0.25		**+2.33**
Case 4	0.25		0.25		0.5		**−4.45**

alternative 2 as the most sustainable. On the other hand, in case 3, in which the economic dimension is dominant, the alternative 1 is the most sustainable *(Act 3.d)*.

4. Conclusions

This work aims at the sustainable design of cultural exhibitions based on the development of a set of sustainability actions: 1-Defining sustainability strategy and prioritizing of sustainability issues; 2-Applying sustainability approaches; 3-Studying sustainability performance for different design alternatives; 4-Checking that sustainability tasks are conducted in a satisfying manner. These actions are included in each of the four phases typically considered in a conventional design process. Its implementation in different case studies has been found very useful to achieve more sustainable designs. Although this research work has been focused on the design of cultural exhibitions, it is thought that these actions contribute to creating a methodological framework to approach and solve different design problems.

Two different types of cultural exhibitions, indoor and outdoor, are studied. Firstly, the design of an itinerary exhibition that requires a wide room for the presentation of artifacts and other contents is examined. Secondly, an exhibition that is developed in the streets of a big city is designed. The development of each case entails a wide number of activities, is supported by numerous systems (products and services) and different stakeholders can be involved. In order to identify the most significant systems, activities, and stakeholders concerned regarding both ecological and socio-economic issues, three complementary approaches are applied in this work: a) life cycle approach, so that all activities involved in the creation, provision, and end-of-life of the cultural services are analyzed; b) flows between system approach, so that those critical product and service systems affecting the exhibition design process, are identified; c) triple bottom line approach, so that indicators of three sustainability dimensions (environmental, economic and social) are evaluated. The application combined of these three approaches has been found very adequate to address the complexity of each design problem.

The selection of the most sustainable alternative is based on the evaluation of indicators for each sustainability dimension. The structured and standardized LCSA methodology as well as specific impact categories for each dimension are used in this work to obtain a quantitative valuation of sustainability, which allows us to objectively compare design alternatives and represents a significant advance in relation to other studies on sustainable service design. Nevertheless, this entails the compilation of a big number of data associated with the overall development of the exhibition's cultural projects. In each case, data on materials used, energy consumed, working times, and execution costs are estimated from the detailed study of activities carried out along the creation, provision, and end-of-life stages.

The methods for planning of cultural services, proposed above, requires the involvement of designers throughout the entire service creation process. The multidisciplinary collaboration of the designer with managers, curators, and technical profiles as well as suppliers is necessary to carry out this method that takes into account multiple dimensions of sustainability. This fact may suppose a limitation in the application of this method by institutions and organizations, whose work flow reduces the designer's role solely to the task of visualizing the ideas of the curators and preparing the technical documentation necessary for production.

The results of the assessments of the sustainability of services depend on the scope defined for the assessment: the time established for the entire life cycle, displacement distances, materials used, etc. Therefore, it cannot be affirmed in a general way that one service is more sustainable than another, but always taking into account the framework of the established scope. Although that can be understood as a limitation of the study it reveals as well the need to develop a more significant amount of sustainability assessment research dedicated to different cultural services, so more general conclusions could be drawn.

The indoor exhibition design was carried out according to those initial requirements established by the cultural institution and considering that the exhibition space layout and the transport of materials between destinations are critical systems. Two design alternatives, focused on the transformation of the showroom area using a modular wall system, are analyzed. The first alternative is based on wooden and not reusable components. The second alternative is based on reusable components made of anodized aluminum, which must be transported between different destinations along with the exhibition artifacts. A comparative review of indicators by systems shows that impacts estimated for the second alternative are higher than those of the first alternative in the transport service but considerably lower in the exhibition space layout. The cultural service shows globally better indicators for the three sustainability dimensions in the second alternative, which is therefore selected as the final design option.

In the case of the outdoor exposition design, it is considered that both exhibitors and exhibited contents are critical systems. Two design alternatives, which mainly differ in the incorporation of lighting, are proposed. The first alternative uses printing content on replaceable vinyl and the second alternative is based on replaceable printed textiles, which can be illuminated when visitors approach. A comparative review of indicators for each sustainability dimension shows that the first alternative globally presents higher emissions and working times but lower execution costs than the second alternative. In order to obtain a global sustainability evaluation, an aggregated index is calculated. It is observed that the alternative most sustainable depends on the different weights assigned to each sustainability dimension. These weights are selected according to the preferences of the decision-makers.

The results of this study showed the need to consider environmental, economic and social aspects of the sustainability of an activity according to a Triple Bottom Line approach. Alternative 2 improves the environmental and social sustainability impacts but the economic one is increased so the sustainability performance of the activity will depend on the decision maker and the weights assigned to each dimension. The success or failure of an activity can not be measured only in terms of profit or losses. It must also be measured in terms of the well-being of society. And even currently the inclusion of cultural impact is argued by some authors as the fourth dimension of sustainability.

The study of these two practical cases using a consistent framework contributes to integrating sustainability considerations in the design process of cultural exhibitions. Future research should expand the application of this framework to sustainably design other types of cultural services as well as more complex systems combining products and services. Further studies including sustainability as a strategic principle in the design of services should be carried out, exploring and comparing the sustainable quality of these results from different design approaches and with greater emphasis on social concerns and different stakeholders. Thus, designers would benefit from tools, techniques and methods to aid them with the sustainability challenge.

Funding details

This work was supported by the Gobierno de Aragón -Grants for the development of R + D + i projects in priority lines and of a multidisciplinary nature for the period 2021–2023, Project' SUSTAINABILITY OF CULTURAL SERVICES AND PRODUCTS. DEVELOPMENT OF A MULTIDIMENSIONAL DESIGN METHODOLOGY'

Author contribution statement

Anna Biedermann: Natalia Muñoz López: José Luis Santolaya Sáenz: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted

the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Irene Ramos Lapesa: Francisco Javier Galán Peréz: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis

tools or data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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