PLANTILLA DE LA MEMÒRIA TÈCNICA DE LA SOLUCIÓ PROPOSADA.

RECIRCULA CHALLENGE 2021

Hub Recircula UPC AMB

SAMO Developers

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INDEX

A VIABILITAT DE LA PROPOSTA

A | VIABILITAT REAL DE LA PROPOSTA	

En aquest apartat s'ha de descriure la proposta i evidenciar la viabilitat real del model de negoci. Per a això, s'ha de proporcionar informació sobre la problemàtica i la deguda justificació sobre la seva viabilitat, tant econòmica com tècnica. Volem idees precises i clares.

A.1 IDENTIFICACIÓ DEL PROBLEMA, OBJECTIUS I SOLUCIÓ PROPOSADA

A.1.1 Identificació del problema: especifiqueu quina és la necessitat o problema que heu detectat. En la definició d'aquest problema o necessitat ha de quedar clar quin és el perfil de públic afectat per aquest problema ja siguin persones, empreses, organitzacions o altres col·lectius.

Informació de suport:

- *El model Canva us pot ajudar a planificar l'apartat A d'aquesta plantilla: públic objectiu, agents clau, identificació del problema, etc.* Link
- *Aporteu dades quantificables (p.ex. bases de dades, estadístiques, estimacions o altres). Podeu utilitzar annexos.*
- *Aporteu exemples o casos reals de la problemàtica o necessitat detectada.*

Negative impacts of existing buildings that require rehabilitation is increasing daily with dramatic consequences, chief of which are the environmental, psychological and financial problems [1]. In Spain, it has been reported that numerous buildings could not satisfy the current environmental, economic and social qualities and they are in urgent needs of rehabilitations. These quality flaws have affected buildings consumed energy, produced emissions and its inhabitants' comfort and their living quality mainly during the COVID-19 pandemic and lockdowns. Long list of researches resulted that a considerable rate of these buildings impacts can be improve by optimizing their façades. Adaptive façade is a pioneering technology in terms of optimizing energy consumption and comfort levels and reducing bills in buildings. However, their application in existing buildings has been lowly developed [2].

By growing the financial crisis in the world, long list of literatures has been investigated the adaptive façades from economic aspect to reduce their final production and maintenance costs. Correspondingly, the generated idea for this project also has special focus on the final production cost of adaptive façade while regulate buildings functioning, energy performance, bills, emissions and appearance attractiveness.

Early evidence on circular economy policies suggests the municipal solid waste as zero-cost alternatives which can be reused as modifiers composition of basic construction materials being foam glass and high-impact polystyrene wastes [3]. Reusing waste in construction while has economic contribution, can also contribute in reduction of environmental impacts. For instance, reusing blast furnace slags and pulverized fuel ashes can make a particular contribution in conserving energy in the manufacture of cementitious materials and of lightweight aggregates [4]. Moreover, reusing waste materials have social benefits for considered society as well. Pons et al, developed three prototypes of solar control devices for schools in Spain with the main tested and evaluated MSW materials in order to increase the pupil's knowledge about their future waste problems [5].

During the 2020, the COVID-19 pandemic has created enormous uncertainty to the world, and changed the profiles of solid waste management [6-8]. In Spain, which is the location for the numerical simulation of the present proposal, a late 2020 survey found moderate changes in waste stream quantities during the COVID-19 pandemic [9]. In the City of Barcelona, residents were advised to no longer put these new sorts of wastes being as personal hygiene/sanitary products, PP (Polypropylene) – see Annex A for abbreviations- face masks, PC (Polycarbonate) face shields and napkins in the organics bin but rather in the garbage One of the other main problems followed by

COVID-19 was the long-term lockdown and consequent inhabitants' emotional, intellectual, occupational, physical and well-being challenges inside the buildings. This problem originated mainly from these buildings required rehabilitations in terms of their lighting, ventilations, aesthetic comfort and living quality. Also, there are some quality flaws that also have influence on both energy consumption and emissions generation, which require rehabilitation specially in the core of their façades.
SAMO developers, considered these new sort of waste materials as an opportunity to develop novel waste-based low-cost adaptive façades for Spanish buildings in order to optimize their sustainability performance. This research project also aims to increase the society knowledge regarding global waste problems by a) collaborating with educational or health centers, and b) users' incorporation on the assembling process of the proposed façade system.

A.1.2 Definició dels objectius del projecte: en base als problemes especificats en l'apartat A.1.1, descriviu quins objectius us proposeu per solucionar els problemes plantejats en l'apartat anterior.
Informació de suport:
- *Definir quins són els objectius que voleu aconseguir amb el vostre projecte aplicant la tècnica M.A.R.T.E., és a dir, definir objectius Mesurables, Assolibles, Realistes, Temporals i Específics.*
- *El Model DAFO us pot ajudar a detectar debilitats a millorar i possibles avantatges de la vostra solució en base els objectius que us plantegeu. Link*

The main objective of the SAMO Developers proposals for Recircula Challenge 2021 is to design and develop a new low-cost, environmentally-friendly and user-friendly applicable adaptive façade technology for the refurbishment of existing architecture. This proposal has been developed considering all sustainability values: economic indicators from LCC phases, environmental indicators from LCA phases, and social indicators. This proposal aims to reduce the energy consumption and emissions generated in the usage of existing buildings as well as increase their inhabitants' well-beings and comfort by improving their a) natural lighting and b) natural ventilation while c) achieving socially accepted aesthetic results. This new developed proposal will contribute on the reduction of the generated COVID-19 waste materials by reusing an important amount of these materials.

A 1.3 Definició de la solució de producte o servei proposat: definir el producte i/o servei capaç d'aconseguir els objectius plantejats en l'apartat anterior especificant de quina manera s'aconsegueixen.
Informació de suport:
- *La proposta plantejada es pot basar en una solució no existent prèviament o en una millora d'una solució existent. En qualsevol dels dos casos, us heu d'assegurar que la solució o millora no existeix en el mercat.*
- *A més de la viabilitat tècnica i econòmica de la solució (que analitzareu en apartats posteriors) la innovació i la creativitat del vostre projecte són dos factors que us ajudaran en la cerca de solucions eficients que puguin marcar un factor diferencial respecte a solucions existents o similars.*
- *Material de suport: resum Manual d'Oslo sobre Innovació link (al final del web, podeu accedir al manual sencer en pdf)*

To achieve such objectives, the results of a previously developed new Multi-Criteria Decision Making (MCDM) tool have been followed in this research proposal [10].
This tool suggests that the generated façade for this proposal required to be: a) movable and adjustable considering user demands and weather fluctuations, b) has an acceptable level of U-value and insulation, c) able to provide view and natural light while avoid glares, d) able to direct wind to interior spaces and provide shading, e) flexible and aesthetically pleasant, f) possible to incorporate maximum waste materials, and g) effortless and quick to assemble and install.
The generated façade solution for overcoming the aforementioned problems in the Spanish architecture plus increased waste following COVID-19 pandemic, have been proposed for the first time. This novel façade technology can provide maximum lighting and thermal comfort, with the minimum assembling and installing costs.

By incorporating renewable energy systems and TiO_2 nano particles in these façade technology, buildings sustainability can also be optimized in terms of sequestrated carbon and energy conversion efficiency which is another novelty of this research project.
The other novelty of this proposal lies on the fact that it has been developed completely with COVID-based waste items and has very simple and safe assembling process which can be used as a utility model for the residents or staff and even students. This way of sustainability rehabilitation with waste materials will have preventing influences by increasing users' knowledge and awareness about the global waste challenges.
Regarding aesthetic values, the design team has proposed multi-dimensional geometry incorporating low-voltage multi-chip LED arrays lights which will provide fascinating night visions for users and pedestrians.
In addition, this proposal for the first time investigates the mechanical behaviors of the several sorts of the COVID-19 waste materials to have minimum toxicity and maximum resistance.

A.2 TREBALL EN XARXA AMB AGENTS CLAU

En aquest apartat s'ha d'analitzar quina és la xarxa d'actors clau de la proposta, tant les aliances que necessitem per concretar el model i enfortir-lo com l'orientació a l'usuari en relació als actors afectats o públic potencial. És un factor de gran importància i en la majoria dels casos determina la rendibilitat del model de negoci i l'impacte en la societat.

Informació de suport:

- *Expliqueu com es pot dur a terme la proposta amb el actors relacionats.*
- *Interactueu amb la xarxa d'actors incorporant-los en el procés.*
- *Podeu utilitzar eines d'anàlisi d'actors,entrevistes, enquestes.*

This research proposal is part of one of SAMO developers members' PhD research thesis, which develops low-cost intelligent facade from waste materials to enjoy the wide range of their advantages in all rehabilitation-required architecture. Until know different real-scale prototypes of waste-based façades have been developed for schools in Barcelona, Spain to increase pupil's knowledge and rehabilitate schools with lowest possible costs. The following presents the, networks and the target community.

Collection:
SAMO developers have succeed to collect COVID-19 waste materials through innovative approaches from encourage people in social medias to agreements with different centers. As first steps, a poster has been shared in Facebook and Instagram to collect the COVID-19 waste items as much as possible which it had also educational influences for the viewers and mostly have incorporated in their classes (See Annex B). As previous experiences, we also have succeeded to present our idea to different centers. For example, in Iranian schools and health centers. These two processes of collecting the waste materials helped us to a) research around how COVID-19 waste materials can be collected, and b) analyze the acceptability of rehabilitating the building façades with COVID-19 idea in society. Figure 1 resenting the collected waste items by pupils in Sweet Baby primary school in Tabriz, Iran.

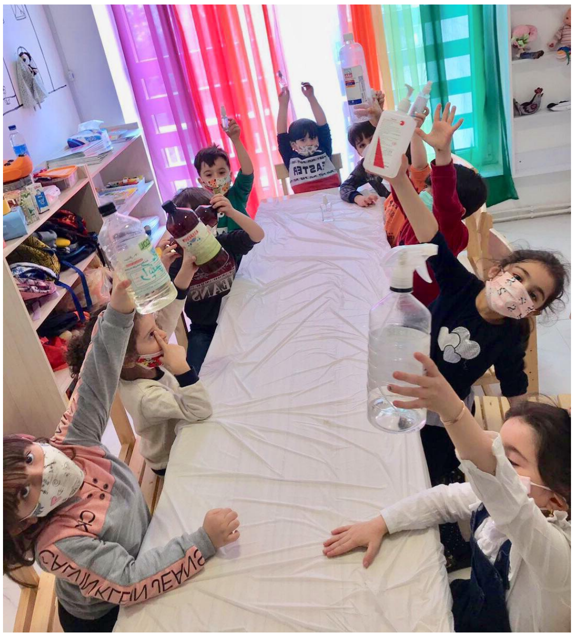


Figure 1. The collected waste in school and pupil's collaboration.

Classification:
Waste items have been collected based on a) certain safety protocols (see section A3.2.2), b) mechanical characteristics (see section A3.2.3), and c) design configuration. Accordingly, two types of PP face masks and different types of PET sanitizer bottles have been considered as qualified material for this research proposal. These considered items have been already explained in detail to the involved schools, health centers and in the social media, as previously explained. Therefore, the collected waste materials have been adapted to the needs of SAMO developers and will be used during the prototypes production.

Marketing:

The key strategies in the marketing of this proposal are two-folded:
a) DIY association: during the first steps of this project, this proposal will be shared with the intellectual protection of a utility model and the aid of booklets and manuals by collaborating NGOs. This utility model will be part of the Do-it-Yourself social movement, so that freelances and organizations will be expected to be incorporated from all around the world. This concept will be provided freely to different social medias and websites such as our previously developed webpage (https://sites.google.com/view/arqescsost/) which targeting educational centers rehabilitations and increased learning performances.
b) Promotion: In this case, SAMO developer's proposal will be offered to different possible private and public organizations and institutions after analyzing the market demand without limiting the geographical locations and target audiences from children to aged generations. However, future investigations and surveys will be done to characterize its influences on different range of societies with different ages or cultures. Expected interested institutions are: the department of education, institutions responsible of public housing provision, institutions responsible of waste management.

A.3 DISSENY, QUALITAT I VIABILITAT TÈCNICA

A 3.1 Metodologia proposada per aconseguir els objectius: és el mòdul on es presenta quins són els passos que s'han seguit per a dur a terme la idea presentada. És important que les accions siguin clares, ja que descriuen COM s'aconsegueixen els objectius.
Informació de suport:
- *Descriure quins són els passos a seguir per a dur a terme el projecte.*

This research project has followed the 3 phases presented in Figure 2. The first phase, has started to identify the problems as explained in previous sections. The second step of first phase has reported the results of previously developed new MIVES sustainability assessment tool. This new MIVES, assessed the sustainability of five outstanding intelligent façade systems and has selected the most sustainable alternatives and technologies and has been provided suggestions and recommendations for future intelligent façades. This assessment has been done considering all three pillars of sustainability and 16 indictors (see Annex C) [10]. This model and its outputs helped SAMO Developers to generate their solution for recognized problems as the third step of first phase. Moreover, this study evaluates the degradation behavior of possible types of COVID-19 waste items

The second phase has generated a new façade technology optimized for the specific problems of Spanish buildings in three steps. The first step searches possible COVID-19 waste items considering various parameters and their aging and mechanical behavior tests. These tests consisted in exposing samples of COVID-19 wastes to natural weathering in a representative location of the application of this research project plus in the experimental prototyping position. The representative site was within Barcelona metropolitan area, Spain, a Mediterranean region with an annual average radiation dose of 4.3 kWh/m^2 [12]. The experimental site was in Tabriz, Iran, (38.0962°N, 46.2738°E).
Steps 2 and 3 have been developed the first theoretical concept, its first 3D model and first experimental prototype. These steps are using Rhinoceros® and its Grasshopper® plug-in, Autodesk Revit® and Autodesk 3ds Max® to analyze the technical features and operational performances of the concept. The experimental prototype has been developed on the external south façade of a typical flat in aforementioned experimental site Tabriz, Iran.

The third phase, evaluates the economic, environmental, social and technical performance of the prototyped and modeled concept. In this phase the feasibility and viability of the concept will be evaluated as well. The concept will be evaluated based on 16 indicators of the new MIVES model, LCC and LCA calculation approaches and numerical tests. During the numerical tests, a room modelled in Revit which was a typical, south-facing perimeter office located in Barcelona, Spain. As the next step, the global sustainability index of the concept is reported. As the final step, will carry out a sensitivity analysis in order to prove the robustness of this research study.
Figure 2 presents this proposal main phases and following steps.

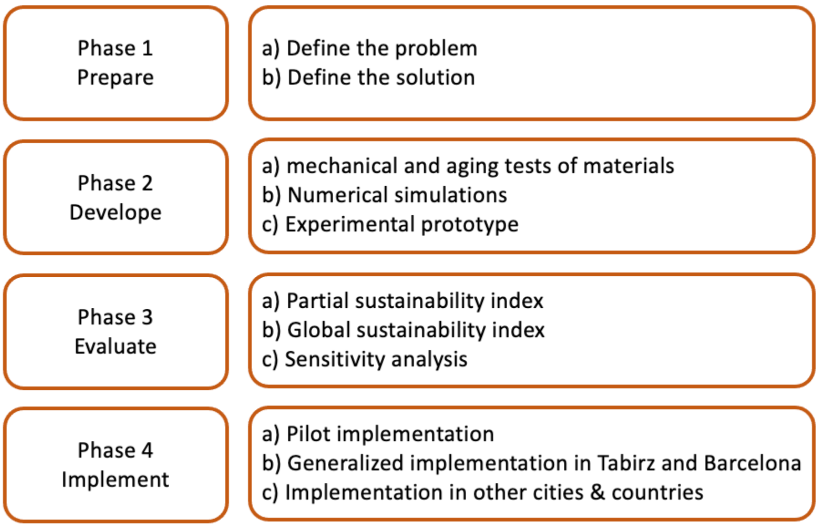


Figure 2. The main phases and following steps of the proposal.

A 3.2.1 Disseny: descripció del disseny del producte o servei. El disseny es considera tant la descripció gràfica del producte o servei con els seus fonaments, això és, dimensions, formes i les toleràncies, així com informació del material que s'utilitza.
Informació de suport:
- *Descriure el disseny de la solució.*

- *Descripció del procés del producte o servei, per exemple mitjançant un diagrama de flux.*
- *Recomanem la utilització d'annexos si disposeu d'imatges dels prototips, renders, assajos o altres.*

Design: The concept features a dynamic shading system consisting of individually movable tiles. The modules are confined to a predetermined geometry inspired by AL-Bahar tower Mashrabiyah façade which has been scored as the most sustainable façade in the MIVES. The design process has been started by developing a 3D model by Rhinoceros® to analyze the operation and movement patterns. Figure 4 shows some views and details of this model. In this design, the shell consists of two 100 x 100 cm rectangle modules, which operate as a kinetic external layer, sitting 50 cm outside the main façade on an independent structure. Each module is sub-divided into eight triangular frames.

The tiles can be raised and folded manually for various functions such as shading, solar gains, daylight distribution, energy saving or energy generation.
Considering the final production cost of the proposal, the main structure, supporting frames, filling materials have been developed by incorporating COVID19-based waste materials. Except Cantilever struts which are stainless steel fixed to the main structure of the building to support the dynamic units. By evaluating mechanical and aging behaviors of COVID-19 waste materials, PP face masks, PC face shields and PET sanitizer containers have been qualified for developing this concept. Moreover, the structure and frames will be arranged by low-voltage multi-chip LED arrays lights which will shine during the nights. Table 1 presents the total amount of waste items among other components used for the 1m^2 of the proposed façade system.

COMPONENT	MATERIAL	QUANTITY
Face mask	PP	30 unit/m^2
Sanitizer bottle	PET	60 unit/m^2
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	2.48 kg/m^2
Cover	TiO_2	0.4 kg/m^2
Connections	Twist ties	1m/m^2
Lighting	5V LED multi-chip LED	8m/m^2

Table 1. the total waste items and components used for the proposed façade system.

Production: The process is starting by transforming the PET container and PC face shields into a structural piece that, together with screws and bolts makes it a very resistant structure. As shown in Figure 4 containers are cut at both ends creating a plastic sheet and rolled into a much more compact and resistant tube. The structure and frames can be developed by joining several of these tubes by drilling and bolting them together. The angled connections of tubes are made with the caps of the bottles and the bases of the bottles, together with the help of some bolts which makes star connections. Once we have the main element, three of them has to be joined by twist ties inside face masks, forming a 50 x 50 cm scalene triangular shapes. The frames of this triangular shape will be filled by LED arrays without using any connections which can be disassembled easily for future uses. This concept uses PP face masks as a solution for closing the module as they block glare while transferring light and protect building from wind and water pass as they has low moisture-absorption rate. These face masks will be connected to each triangle tubes by their own threads. Once the triangles have been assembled, the module is assembled by joining eight triangles with others using the same face mask twist ties. At the end, all components will be covered with TiO_2 nanomaterials referring its proven features in previously carried out study [11]. As presented the introduced assembling process is considerably simple while used materials are safe to be used. Figure 3 presents the modules key components and connections which their assembling process have been illustrated in Figures 4 and 5.

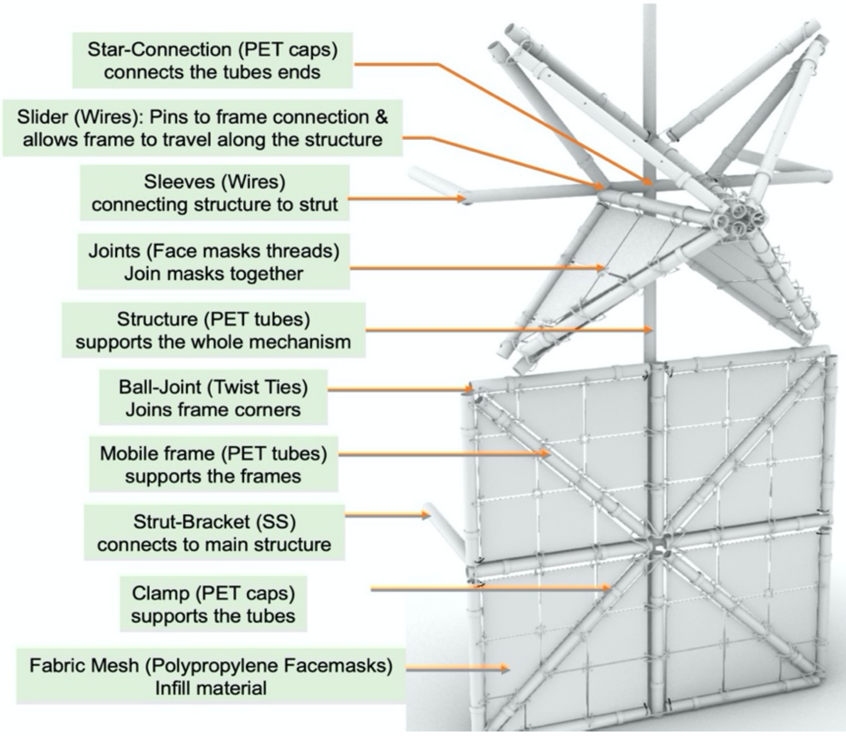


Figure 3. The key elements and components that make up the SAMO Developers proposal

Figure 4. Assembling process of the proposal

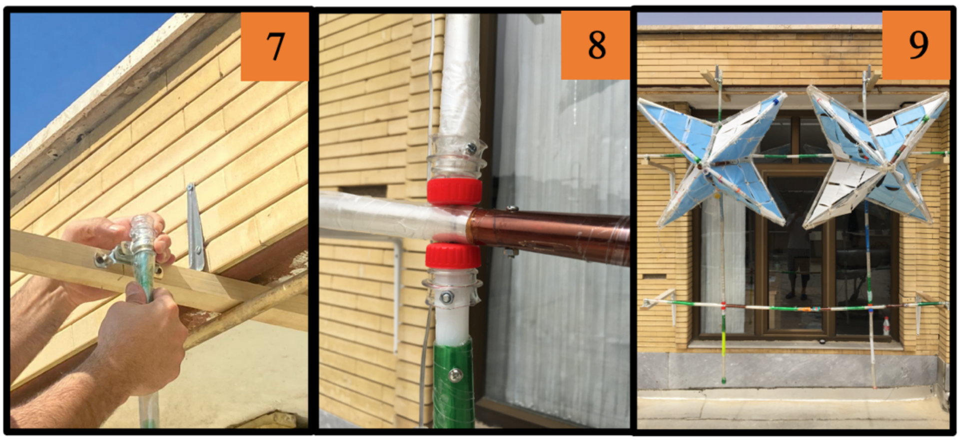


Figure 5. Assembling process of the proposal

Our first full-scale proof of concept prototype, shown in Figures 6. The SAMO Developers prototype is 2x2 m and contains 32 individually modules. The prototype has been developed for a typical room in Tabriz, Iran with the daily average main conditions of: irradiation from 15.27 MJ/m^2, rainfall 79.7mm, temperature from -11 to 38 ◦C and with an average relative humidity of 74%. The dimensions of selected room are 4.8x3m with WWR of 30% and U-value equal to 1,6 W/m²K. To monitor the thermal comfort, temperature, humidity and illuminance sensors have been deployed inside the room in both before and after application of the prototype. As the future steps, feedback from the occupants will also be gathered through behavioral studies. The façade has been fabricated and assembled in 55 hours using minimum use of machinery and equipment.

Figure 6. a) The day view of the first developed prototype, b) The night view of the first developed prototype.

A 3.2.2 Qualitat: volem propostes específiques relacionades amb el producte/serveis i la seva qualitat, això és, l'adequació a l'ús. La qualitat recull els requisits que ha de complir el producte / servei, tant funcional com estètic i les degudes normes de compliment i funcionament.

Informació de suport:

- *Es valorarà que les propostes (producte o servei) i la seva qualitat siguin específiques.*
- *En l'edició Recircula Challenge 2021 cal tenir en compte les normes i recomanacions associades a la Covid-19.*

This section details the quality considerations for the SAMO developers' concept. The current design has three key elements: 1) shading panel consisting of 8 scalene triangle modules, 2) supporting structure, and 3) connection slider between structure and panel. All these elements are made of COVID-19 waste items and connection bolts.

Technical performance: dynamic panels are supported by stainless-steel strut-bracket arms 700 mm from the frame of the building. This offset enables the panels to attain a fully open and fully closed positions without interfering with the structure. In addition, it provides a thermal buffer zone, solar preheating of ventilation air, energy saving, sound protection, wind and pollutants protection, night cooling and space for energy collection devices like VAWT (Vertical Axis Wind Turbines). The innovative structure is made by rolling the PET bottles and making 1-inch tubes which have the required strength and stiffness. Moreover, the concept has acceptable level of reaction against wind and rain water which makes this solution to be used as other applications like areas that have suffered natural disasters, together with a covering, so that the space is habitable. In addition, the LED strips have been arranged inside the PET tubes and are technically and electrically protected. The structure and shell have the weight of 1.8kg/m^2 which were designed to withstand an approximated wind load of 100N/m^2 (corresponding to a windspeed of E70 km/h). Although, wind-loads may cause horizontal movements up to ± 100 mm. The system is restricted from any vertical movements and are absorbed by the flexibility of the structural frame.

Safety: In this proposal, the users of buildings are the main contributors of its assembling and installing process. Accordingly, SAMO Developers have considered three levels of safety protocols and precautions for this proposal to provide maximum safety for all participants.

The first level of protocols considers user safety against COVID-19 virus spread in accordance with legal guidelines. This protocol suggests that the collection of waste items should be done with gloves and face masks. Moreover, it suggests that the collected materials they should be quarantined for a minimum of 72 hours to protect assembling members.

The second safety protocol level is protecting members from probable damages or injuries during the assembling and installing process. This protocol suggests: a) use of highly safe and reliable tools, b) minimum use of risky and sharp wrenches, c) use of bolts and nuts instead of risky adhesives or welding, and d) regularly wash hands with an alcohol-based hand rub or clean them with soap and water.

The third safety protocol level protects buildings users and pedestrians from the damages which can occur after assembling the façade, such as disporting, rupture or possible falling of parts. This protocol suggests maximum wind load bearing and fire resistance previsions during design and material selection process.

Accordingly, several safe, major and disinfect-able COVID19-based waste items have been studied regarding their mechanical and degradation properties in the following sections. These safety protocols will be provided to the users and urge to clearly follow these precautions before intending to implement the proposed façade system.
]

A 3.2.3 Viabilitat tècnica: s'ha de demostrar la viabilitat tecnològica per a generar una solució/producte innovadora. Entenem que és viable tecnològicament quan existeix tecnologia que és capaç de produir el disseny especificat complint amb la qualitat requerida. Per a això s'haurà d'aportar informació sobre la maduresa de la tecnologia que s'utilitzarà.

Informació de suport:

- *Es valorarà que la viabilitat tecnològica estigui justificada amb evidències.*
- *Es valorarà la innovació de la tecnologia utilitzada.*

This proposal feasibility relies on the appropriate durability and fire properties of its materials, which satisfy the design requirements for the aforementioned market and case studies that the proposal aims to satisfy. The required durability of this research proposal is considered to responds to the 1-year duration for the Spanish architecture. This level of durability has been reported as eligible material for façade development relying on the previously obtained results that exclusively studied one-year weathering and laboratory aging behaviour and mechanical performance of household waste components [11]. The reports showing that the tensile strength of the used waste materials composed decreased due to the UV aging. Moreover, these materials are approved to be used in the exterior conditions as well as the main joints and stapled joints. Furthermore, a service life of 10 years for non-structural parts of the proposal is expected specially by applying TiO_2-based paint containing Disperlith foodgrade Elastic treated with Disperlith Primer which achieved the highest durability performance. After this year, the 97% of the concept can be reused if they maintain the required properties or otherwise recycled by a second processing cycle.

The aging test of PP face masks and PC face shields has been caried out in natural weathering from December 2020 to April 2021. While the mechanical and aging test of PET containers, thread joint and twist ties joints have been evaluated in previous research study on various items of MSW items from 2017 to 2020.

This test consisted in exposing samples of a) PP face masks and b) PC face shields to natural weathering in a representative location of the application of this research project plus in the prototyping position (see section A3.1). The both tests carried out during five months and will evaluate till 12 months, which is the aforementioned aimed durability of the project. Table 2 present the results of the natural weathering aging tests as well as images of the original and aged samples. The images are showing that these tests degraded the studied samples which were involved: a) sheet separation and distortion in PP face masks; b) yellowing of the both sample types.

Component	Material	Test time	Shsp	Sw	Dist	Yell	New sample	Aged sample
Face mask	PP	5mo	4mo	-	5mo	4mo		
Face shields	PET	5mo	-	-	-	5mo		

Table 2. Main results of the natural weathering aging tests.

Legend: mo: months; ShSp: sheets separated; Sw: swelling; Dist: distortion; Yell: yellowing.

The fire properties of the selected waste materials have been reported in the literature. As shown in Table 3, these COVID-19 waste items have a poor behaviour exposed to fire as other synthetic polymers and shouldn't be exposed with fire. Considering their TTI, PP face masks has the lower coefficient followed by PET.

Component	Material	TTI (s)	References
Face mask	PP	23	[13]
Face shields	PET	40	[14]

Table 3. Fire properties of selected covid-19 waste materials.

Legend: Time to Ignition (TTI), Total Heat Emitted (THE).

Accordingly, the analysis and tests resulted that the studied materials are good façade components. Moreover, the concept it is robust, lightweight, and is designed to resist the following:

- High exposure to UV solar rays and atmosphere temperatures reaching up to 49 degrees.
- Humidity reaching up to 100% during summer.
- Corrosion – if the building faces the sea or exposed to high levels of sand and dust.
- High wind-loads and wind speeds up to 100N/m^2 and 70 km/h respectively.
- Fire up to 1 hours for the main supporting frame, as it is comprised of steel components.

B| IMPACTES	SOCIALS AMBIENTALS ECONÒMICS

L'objectiu és que compartiu la visió sostenible global de la vostra proposta. Per a això, heu d'explicar com la idea i el model proposat poden fomentar tant l'economia circular, com la inclusió i la responsabilitat social. S'avaluen els resultats socials, ambientals i econòmics del projecte.

Podeu utilitzar aquesta guia orientativa en economia circular per a fer un autodiagnòstic del vostre projecte i assegurar la circularitat de la vostra proposta.

Com els criteris han de ser fàcils d'usar tant per als dissenyadors del projecte com per als avaluadors d'aquesta, s'han classificat els resultats de la següent manera:

- Els resultats socials han de ser una estimació de la repercussió del projecte en els aspectes d'índole social. S'haurà d'argumentar el raonament dels resultats exposats.

- Els impactes ambientals es reporten mitjançant una taula amb indicadors per a mesurar el consum de recursos i la circularitat dels projectes. L'estimació de les mètriques que es proposen han d'estar ben argumentades.

- Finalment, s'haurà d'evidenciar els resultats econòmics que s'esperen del projecte. Es proposen una sèrie d'eines són molt necessàries en el món dels negocis, i que serveixen per a mesurar la rendibilitat de la proposta.

B.1 IMPACTE SOCIAL: RESPONSABILITAT SOCIAL, INCLUSIÓ I IMPACTE A LA SOCIETAT

Les iniciatives d'Economia Social i Solidària estan presents en tots els sectors de l'activitat econòmica, des de l'energia fins a la cultura o l'alimentació. Plantegeu propostes i iniciatives en relació al vostre projecte que contribueixin a l'Economia Social i Solidària.

Informació de suport:

L'Economia Social i Solidària és el conjunt d'iniciatives socioeconòmiques, formals o informals, individuals o col·lectives, que prioritzen la satisfacció de les necessitats de les persones per sobre del lucre.

- *Guia pràctica sobre Economia social i solidària* aquí
- *Portal web de La Xarxa d'Economia Solidària (XES):* link
- *Pla d'impuls de la XES de l'Ajuntament de Barcelona:* link

The social impacts of this proposal have been assessed based on the social indicators from MIVES requirements tree (see Annex C). These indicators analyze the values that this proposal can provide to users during its production and using phases; these include safety values, construction values, appearance and different dimensions of comfort levels. These indicators analyze the partial social sustainability of developed façade concept and each one has measurable variables from 0-10 that have been used to quantify this new proposal. The following paragraphs detail this proposal social impacts based on these five indicators.

a) **Fabrication and assembling easiness:** this indicator evaluates the production and assembling ease depending on a system being low-tech or high-tech, plus its simplicity. Adaptive façade technologies often involve innovative technologies, resulting in challenging projects with relatively high risks. Project developers tend to take conservative attitudes to adopt this type of new technology because the risks are associated with chances for disproportionate fabrication and assembling time and required highly professional experts to design, analyze and develop. The proposed façade concept has been planned to develop by users in order to reduce costs and increase their knowledge on global waste problems.
The designed geometry avoids major twisting, bending and stretching of components while going from one opening configuration to another. The designed structure as well, is quite simple and has clear assembling process which can be fabricated by all ages from children to aged generations. In addition, the design process has considered the risks of rattling and vibration during use phases and achieved the minimum required maintenance specially in high levels. Thanks to the lightweight structure and materials used in the concept, the need for scaffolding and large cranes has been eliminated and the process is comparatively effortless. The application of TiO^2 cover was assumed to be done with a roller resulting in no losses during the application.

b) **Flexibility:** evaluates the flexibility of the proposed façade system and repercussion of it in the rental price considering the novelty of the systems, appearance, reliability, and acceptancy. The proposed system is able to continuously adapt its layout to evolving environmental needs. By considering the economic indicators, the proposed façade can operate by manual devices and provides value to user by their interaction to adapt their environment to their own requirements and increase the acceptancy of proposal. In addition, it turned into resistance and reliable options as well, if has been produced with attention and precision. The proposed flexible façade also is able to increase the property value by provided aesthetic option. TiO_2 is a silver-white metallic element which its application provides a good strength and excellent corrosion resistance for façade.

c) **Ventilation performance:** assesses orientation and movements of the façade components in line with passive transferring of the wind direction into spaces and provided fresh air and natural ventilation. Architects typically choose natural ventilation to provide the maximum comfort hours for users, reduce emissions and reduce energy consumption. The proposed concept has good level of the ventilation performance by provided passive ventilation and contaminants sequestration. The façade acts as a DSF (Double Skin Façade) system with the predicted 50cm space between the main façade of building and new layer which can provide natural ventilation about 60% of the year. This ventilation among applied TiO_2 cover can considerably improve the air quality in interior spaces. Moreover, the relative humidity has been predicted to decline up to 15%.

d) **Lighting performance:** A well-designed façade can enhance the daylighting performance by regulating solar radiations and glare. By responding dynamically to the changing environmental context, the proposed façade system has a major impact on the amount of natural daylight admitted into the building and reduces the cooling loads required for air-conditioning. SAMO developers investigate the potential impact of the proposal on the daylighting performance of building façades through the selection of the optical properties. The study focuses on perimeter offices in the Mediterranean region in Barcelona, Spain. A room modelled in Rhinoceros® which was a typical, south-facing perimeter office located in Barcelona, Spain (latitude 43.7°N). The three-section façade concept was applied with Window-to-Wall ratio of 50%. The office dimensions are 4m (width) x 5m (depth) x 3.2m (height). Three different configurations of the proposed concept were simulated: 10%, 50% and 100% (Figures 7). The minimum value of 10% was selected in order to ensure a minimum view to the outdoors. For this study, the continuous Daylight Autonomy (cDA) [16], and the spatial Daylight Autonomy (sDA) [15] metrics are used to evaluate the annual daylighting/lighting performance during the 1827 occupied hours (8:00 to 18:00).

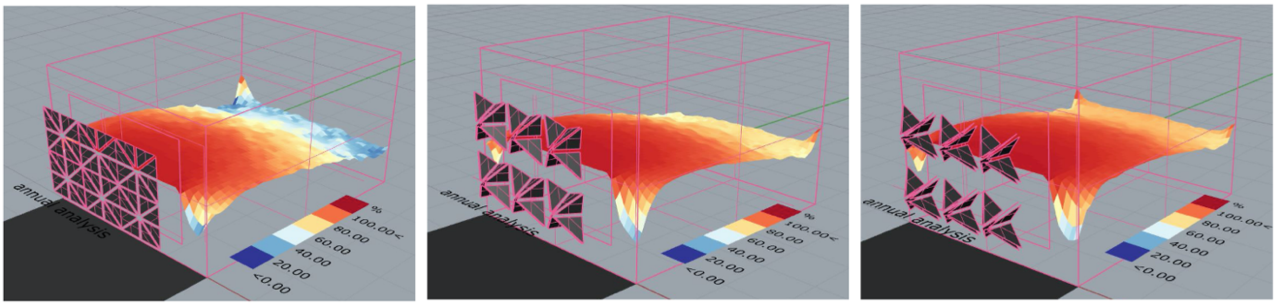


Figure 7. The annual analysis of capital Daylight Autonomy in three different configurations as a) 10% visibility, b) 50% visibility, and c) 90% visibility.

Annual cDA are presented, for the center line of the office, as the percentage of occupied hours where the minimum work plane illuminance levels of 300 lx are met. Annual sDA are presented as a percentage of the entire office workplane where the minimum workplane illuminance levels of 300 lx (sDA300lx/50%) are met for 50% of the occupied hours. All of the simulation results are presented in Figure 8 as a function of the visible effective transmittance of the proposed façade.

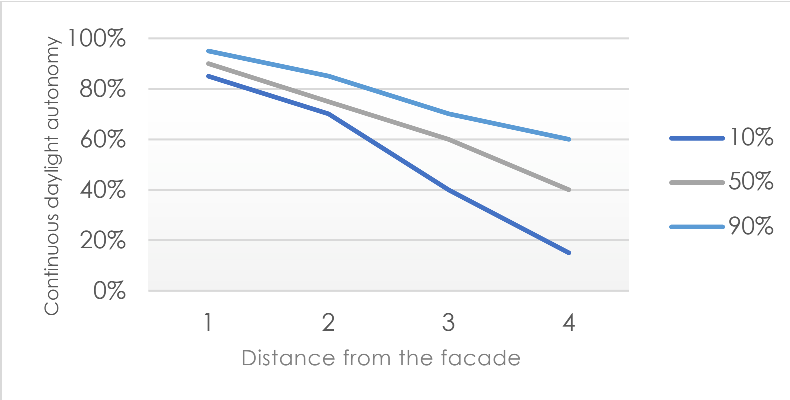


Figure 8. The annual continuous Daylight Autonomy in three configurations.

As shown the design team have been successfully admit natural diffused light into the building and maintain a useful daylight throughout daily working hours (08:00 am to 18:00 pm) with the PP face masks light transmission co-efficient of 20% [17]. After application of the real-scale concept, light sensors located at the perimeter of the ceiling in different distances read average of 450lux and maintained the required comfort. Moreover, other benefits include increased visibility and privacy, a unique and iconic aesthetic, and overall quantitative and qualitative improvements have been achieved after application. As shown in Figure 9, the concept also reduces solar glare, while providing better visibility by avoiding dark tinted glass and internal blinds that distort the appearance of the surrounding view.

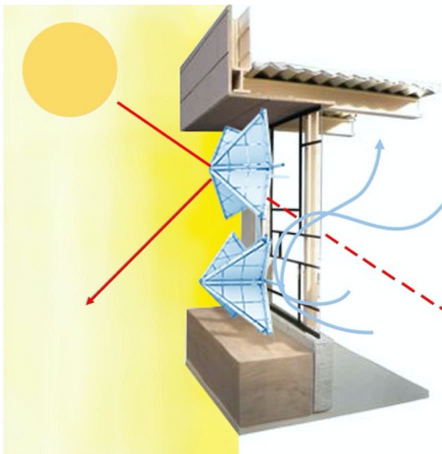


Figure 9. The different effect of the proposed façade in terms of visibility, admission of natural light and overall working space quality.

Table 4 presents the total light performance of the proposed façade system in both before and after application scenarios which done by numerical and experimental simulations.

Value	Coefficient before application	Coefficient after application	Simulation model
Illuminance	2600 Lux in 75%of the office	300 Lux in 75%of the office	Numerical + Experimental
Light transmission	100%	20%	Literature
UV light-filtering	55% by tempered glass	75% (2mm PP layer + Tempered glass)	Literature
Improved daylight	NA	70–150%	Numerical + Experimental
View	100%	80%	Numerical + Experimental

Table 4. The light performance of proposed façade before and after application.

e) **User safety:** Design for safety is still in a nascent stage which is a growing demand for it in terms of fire resistance, toxicity and user wellness among the decision-makers in the construction industry, particularly pertaining to the façade. SAMO Developers by taking into account different safety considerations they have been avoided from these risks. According to the aforementioned fire tests references for PET and PP [14] all these household waste containers have a poor behavior exposed to fire. At temperature above 100 °C polypropylene dissolves in aromatic hydrocarbons, such as benzene and toluene [18]. On the other hand, application of TiO_2 has the most positive impact on the environment and human Health by decomposing harmful organic compounds, killing bacteria and eliminating odors. However, producers suggests that TiO_2 should be applied on surfaces with great care.

B.2 IMPACTE AMBIENTAL: CIRCULARITAT, VISIÓ SISTÈMICA I EFICIÈNCIA EN L'ÚS DELS RECURSOS

Expliqueu les millores en el context de l'economia circular. Heu de calcular les millores en relació a l'ús de recursos, energia i ocupació verda així com descriure quina estratègia d'economia circular segueix el model que es presenteu.

Informació de suport:

- *Avaluació de les millores del projecte en termes de recursos i energia.*
- *Explicació de l'estratègia de l'economia circular que s'aplica.*
- *Mesurar els indicadors que es proposen per a quantificar com de circular és el projecte i quins impactes ambientals té.*

This research proposal in all LCA phases has evaluated potential impacts of production, transportation, assembling, use and waste management of the developed façade concept. This assessment has been carried out following previous MIVES model in three levels as fabrication phase, use phase and end of life phase and based on six indicators as a) Embodied energy, b) Embodied carbon, c) Annual energy saving, d) Energy conversion efficiency, e) Sequestrated carbon and f) Recyclability. This proposal also assessed all suggested indicators of this template as material qualities and durability.

a) **Embodied energy:** assesses the amount of energy required in two phases of fabricating and assembling of the proposed façade in KWh/m^2. As mentioned before, one square meter of the concept has been assembled using 30 PP face masks (17x19cm), 60 PET sanitizer bottles (28x8cm), 1 stainless steel strut bracket pipe (70x4cm), and finally 0.4litre of TiO_2 cover. Except drilling bottles, the whole assembling process is done by manual devices without using electricity. The used machine is a small size 50/60HZ drilling machine with the rate of 6bottle/minute which accounted for less than 0.01% of the whole life cycle. Table 5 presents that the consumed energy for each square meter of proposed façade is 104.41 kWh, which 40% of this energy has been saved by reusing face masks and bottles.

Component	Material	Embodied energy	Quantity	Value	References
Face mask	PP	0.01-0.03 kWh/unit	30 unit/m^2	0.3-0.9 kWh/m^2	[19]
Sanitizer bottle	PET	0.58 kWh/unit	60 unit/m^2	34.8 kWh/m^2	[20]
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	22.91 kWh/kg	2.48 kg/m^2	56.81 kWh/m^2	[21]
Cover	TiO_2	30.5 kWh/kg	0.4 kg/m^2	12.2 kWh/m^2	[22]
Multi-chip led	PCB Silicon	Not available	8m/m^2	Not available	-
Total EE per each square meter				**104.41 kWh/m^2**	

Table 5. The total embodied energy of the proposed façade.

b) **Embodied carbon:** considers CO_2 emissions during production and assembling phase. Table 6 presents these values for SAMO Developers concept in detail. The total amount of EE for each square meter of the proposed concept is 19.46 $kgCO_2$ which stainless steel production has the most environmental impacts. However, this amount can be recovered during the first 3 months of use.

Component	Material	Embodied carbon	Quantity	Value	References
Face mask	PP	59 gCO_2-eq/unit	30 unit/m^2	1.77 $kgCO_2/m^2$	[19]
Sanitizer bottle	PET	58 gCO_2-eq/unit	60 unit/m^2	3.48 $kgCO_2/m^2$	[20]
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	4.53 kg CO_2/kg	2.48 kg/m^2	11.23 $kgCO_2/m^2$	[21]
Cover	TiO_2	7.47 $kgCO_2$/kg	0.4 kg/m^2	2.98 $kgCO_2/m^2$	[22]
Multi-chip led	PCB Silicon	Not available	8m/m^2	Not available	-
Total EC per each square meter				**19.46 $kgCO_2/m^2$**	

Table 6. The total embodied carbon of the proposed façade.

c) **Energy saving:** measures the amount of energy that can be saved in kWh/m^2 facade. This indicator analyzes the U-value and ability on controlling solar radiation and heat during summer and winter and resulted saved energy by cooling and heating systems. The U-value can be obtained according to Equation (1) [23].

$$U = 1/Rt \quad \text{Equation (1)}$$

Where Rt is the total Thermal Resistance of the element composed of layers (m2K/W) and can be obtained according to Equation (2).

$$Rt = Rsi + R1 + ... + Rn + Rse \quad \text{Equation (2)}$$

Where Rsi is Interior Surface Thermal Resistance, Rse is exterior surface Thermal Resistance, and R1, is Thermal Resistance of each layer which is obtained according to Equation (3).

$$R = D / \lambda. \quad \text{Equation (3)}$$

Where D is material thickness (m) and λ = Thermal Conductivity of the material (W/Km). By considering the thickness of 0.003 and the K-value (thermal conductivity) of 0.11W/Km and density of $0.85g/m^3$ for pp face masks [24], the U-value of the proposed façade has been resulted as 5.069 W/m^2K.
Furthermore, the research studies around Al-Bahar tower façade, confirms that Mashrabiyah geometries and its movement patterns can reduce Heat by 20%, provide shading effect by 80% and the total energy saving by 20% from lighting and 40% from heating and cooling [25].
By taking into account the obtained U-value and light transmission co-efficient of 20% [19] for PP face masks (as filling material) and added TiO_2 cover, the total energy saving of 15% for lighting and 25% from heating and cooling has been calculated.

d) **Energy conversion efficiency:** the ratio between the useful output and input energy of the proposed façade during the usage phase is the energy conversion efficiency. This ratio can be negative, neutral or positive is depending on the used energy by sensors or mechanical equipment, and the generated heat and/or electrical energy in an intelligent facade technology. This research proposal in the future steps will integrate the green energies in its proposals being as application of PV tiles or small-scale wind turbines to produce the part of required energy for the building. By the way, this rate for the proposed façade system is -1.2% due to consumed 120 watts of energy by multichip LED arrays in 1 square meter.

e) Annual sequestered emission: Proposed façade system can contribute on CO_2 reduction in two methods as a) absorbing emission and b) reducing consumed energy. The amount of CO_2 reduction by façade system will depend on the design, the available façade area, the height of the building, and the climate conditions at that particular site. Based on previously done MIVES assessment, the use of Photocatalytic TiO_2 paints will actively contribute to the absorption of chemical pollutants 0.26 $g/day/m^2$ [10]. Moreover, the contribution of facade on energy saving of the Building results 0.47 TCO_2/year by used mechanisms. Accordingly, 0.48 TCO_2 Can be sequestrated by 1 square meter of the proposed façade system in each year.

f) **Recyclability:** recycling of demolished wastes can either help relieve the landfill capacity and energy from existing building materials. However, recycling of COVID-19 waste items is a challenging process and authorities in many countries have been agreed to dispose them instead of recycling to reduce the virus spread. Although there is a lot of social activities and companies have been raised to criticize the global waste problems of COVID-19. TerraCycle® company, recently have been developed Zero-Waste-Boxes for health centers and they collect and recycle the dominant PPE wastes of COVID-19. As an example, they have densifying the polypropylene-dominant mixture from the face mask into a crumb-like raw material that's used in plastic lumber and composite decking applications. Or the elastane or rubber band portion is ground into a fine mesh regrind and mixed with recycled plastics as an additive to provide flexibility and malleability to products. In Addition, gloves are processed into a rubberized powder which is used for flooring tiles, playground surface covers and even athletic fields [26]. Table 7 presents the 94% recyclability rate of proposed façade and detailed components recyclability in End-Of-Life phase.

Component	Material	Recyclability	Quantity	Debris	References
Face mask	PP	95%	30 unit*3.5g/m^2	6 g/m^2	[27]
Sanitizer bottle	PET	100%	60 unit*68g/m^2	Zero	[28]
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	100%	2.48 kg/m^2	Zero	[29]
Cover	TiO_2	0%	0.4 kg/m^2	400g/m^2	-
Multi-chip led	PCB Silicon	90%	0.3kg/m^2	30g/m^2	[30]
Total debris per each square meter				**436g/m^2**	

Table 7. recyclability of the proposed concept and it's all components

d) **Reusability**: In this research proposal, the practice of dry connections with bolts and nuts and making them visible, allows materials to be easily, cost-effectively and rapidly taken apart and directed for further reuse as shown in Table 8. Reusing of material is practically new in construction sector which is replacing with recycling in near future and needs more researches around.

Component	Material	Recyclability	Quantity	Reusability
Face mask	PP	0%	30 unit*3.5g/m^2	0%
Sanitizer bottle	PET	100%	60 unit*68g/m^2	100%
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	100%	2.48 kg/m^2	100%
Cover	TiO_2	0%	0.4 kg/m^2	0%
Multi-chip led	PCB Silicon	100%	0.3kg/m^2	100%
Reusability of 1 square meter				**97%**

Table 8. Reusability of the proposed concept and it's all components

SAMO developers for further observations, they have been assessed the environmental impacts of the proposed façade based on t the suggested indicators of this template. Table 9 presents additional information around the environmental performance of the proposed façade system. The total weight of the proposed façade has been calculated as 7,06kg/m^2 including 2,48kg/m^2 of Strut-Bracket, 4,08kg/m^2 PET bottles, 0,1kg/m^2 PP face masks and 0,4kg/m^2 TiO_2 cover. As shown the considered durability of 1 year for the concept has been satisfied in all components which TiO_2 cover for facemasks have been increased its resistance and durability up to 50%. However, Tio2 application requires precautions to avoid probable respiratory allergies as be classed as a category 2 under REACH Regulation [31]. In addition, the cover to keep its performance need to be renewed after 3 years [28].

Component	Description		Face-mask	PET bottle	Strut-bracket	Cover	Concept
Durability	Service life		2 years	20 years	50years	3 years	2 years
	Improved service		50%	NA	NA	NA	20%
Material flow	Raw material		Zero	Zero	Zero	100%	5%
	Recycled raw material		Zero	90%	90%	Zero	83%
	Recycled material in concept production		100%	100%	Zero	Zero	92%
	End-Of-Life	Recycle	100%	100%	Zero	Zero	95%
		Reuse	Zero	100%	50%	Zero	74%
		Biodegradable	Zero	Zero	Zero	90%	5%
	Water consumption		Zero	0.18m^3/m^2	0.69m^3/m^2	Zero	0.87m^3/m^2
Quality	Hazardous products		Zero	Zero	Zero	20%	1%
Energy flow	Embodied energy		0.7kWh/m^2	34.8kWh/m^2	56.81kWh/m^2	12.2kWh/m^2	104kWh/m^2
	Renewable energy		Zero	Zero	Zero	Zero	Zero
Emissions	Embodied carbon		1.7kgCO$_2$/m^2	3.4kgCO$_2$/m^2	11.2kgCO$_2$/m^2	3kgCO$_2$/m^2	19.4kgCO$_2$/m^2
	Liquid waste		Zero	Zero	Zero	Zero	Zero
	Solid waste		0.006kg/m^2	Zero	Zero	0.4kg/m^2	0.406kg/m^2

Table 9. The environmental impacts of proposed façade system.

The pre-rationalized model of the innovative proposed façade, with its focus from the very beginning on a ‘design for constructability approach’ allowed the maximum use of COVID-19 waste by 74%. Interestingly enough, the team has been able to bring the level of waste down to 3% to 5% on this project. The sharing of design principles through the MIVES played a large role in this achievement.

B.3 IMPACTE ECONÒMIC: VIABILITAT COMERCIAL (COSTOS / BENEFICIS) MERCAT POTENCIAL I VIABILITAT

La viabilitat de la solució presentada no només ha de ser viable des d'un punt de vista tècnic i de circularitat, sinó també des d'un punt de vista econòmic. En aquest apartat heu de calcular i justificar degudament quin és el cost de producció del vostre producte i/o prestació del servei tenint en compte els costos d'escala ja que no té el mateix cost produir 100 unitats que 10.000 unitats. En base aquest cost base, cal definir un preu de venda justificable des d'una perspectiva comercial i tenint en compte el tipus mercat al qual us adreceu i al perfil d'usuaris que creieu que adoptaran la vostra solució.

Informació de suport:

- *En la següent guia podreu veure els principals elements a tenir en compte per calcular el cost de producció i un preu de venda : link.*

The design and production of the SAMO developer’s façade, involved the creation of a large-scale solution that demanded careful design, engineering and optimisation in order to control costs. Any benefits, advantages or other justification, for every single element, was heavily challenged, based upon their associated a) fabrication and assembling cost, b) annual maintenance cost, and c) dismantling cost. The following section details these values in euros/m^2 for the proposed façade.

a) **Fabrication and assembling cost**: include the costs of design, fabrication, transportation and installations, which is a significant while inevitable indicator. Table 10 presenting the global fabrication and assembling cost of the developed concept. As shown the total fabrication cost of such an adaptive façade is very low comparing the other technologies due to the substituted waste materials as structure and filling components. This process of reducing the fabrication cost can be applied in all construction or rehabilitation process by good understanding of waste features.

Component	Material	Value	Quantity	Price	References
Face mask	PP	Zero	30 unit/m^2	Zero	-
Sanitizer bottle	PET	Zero	60 unit/m^2	Zero	-
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	Fabricate: 5,08 €/kg Include transport and labor	2.48 kg/m^2	12,59 €/m^2	[21]
Cover	TiO_2	1400-1600 €/t.	0.4 kg/m^2	6,1 €/m^2	
Multi-chip led	PCB Silicon	120 €/50m	8m/m^2	19 €/m^2	[33]
Total fabrication and assembling cost per each square meter				**37,69 €/m^2**	

Table 10. The partial and complete fabrication and assembling cost of the developed concept.

b) **Annual maintenance cost:** The term maintenance cost refers to any cost incurred to keep proposed façade in good functioning condition. These costs may be spent for the general maintenance of items like cleaning, repairing, replacing or technical revision. The maintenance process of adaptive façades, required highly professionals and long list of maintenance problems which can be solved by simplifying them and using low-cost materials. Moreover, application of TiO_2 totally eliminates the required cleaning cost for the proposed modules. Its super-hydrophilicity helps the surface dry faster, and prevent the undesirable water streaking or spotting on the surface. Following Table 11 presents in detail the maintenance cost of different IF alternatives in literature.

Component	Material	Maintenance	Quantity	Price

Face mask	PP	Renew once per year	30 unit/m^2	Zero
Sanitizer bottle	PET	Zero	60 unit/m^2	Zero
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	Zero	2.48 kg/m^2	Zero
Cover	TiO_2	Renew after 3 years	0.4 kg/m^2	3 €/m^2/a
Multi-chip led	PCB Silicon	Zero	8m/m^2	Zero
Annual maintenance cost of 1 square meter				**3 €/m^2/a**

Table 11. Annual maintenance cost of the proposed concept.

c) **Dismantling cost:** Existing façade systems going to be restructured or demolished after their end-of-life phase. Such reconstruction interventions cause high bills, resource consumption and waste generation. This section deals with deconstructing and dismantling costs of proposed façade so as to recover as many parts as possible without leaving any debris on site. Table 12 showing the dismantling cost of the IFs and the main recovery potentials of their parts.

Component	Material	Labor	Quantity	Price	References
Face mask	PP	Zero	30 unit/m^2	Zero	-
Sanitizer bottle	PET	Zero	60 unit/m^2	Zero	-
Strut-bracket 70x5cm	1.4462 Duplex Stainless steel	0.36€/kg	2.48 kg/m^2	0,9€/m^2	[32]
Cover	TiO_2	Zero	0.4 kg/m^2	Zero	-
Multi-chip led	PCB Silicon	Zero	8m/m^2	Zero	-
Dismantling cost of 1 square meter				**1€/m^2**	

Table 12. Dismantling cost of the proposed concept in end-of-life phase.

## C| CONCLUSION	PARTIAL SUSTAINABILITY GLOBAL SUSTAINABILITY SENSITIVITY ANALYSIS

This research proposal has applied a recently developed MIVES assessment model able to quantify the sustainability of intelligent facades for the first time with a sensitivity analysis. This assessment model exclusively incorporates main indicators, from energy efficiency to social values. The application of this new model has proposed a new façade technology with the highest sustainability and partial satisfaction indexes as shown in Table 13. The developed proposal is a combination of assessed technologies, which provided a wide range of rehabilitation possibilities. This new proposal has been developed due to its low total production cost, while it will provide maximum energy efficiency, comfort and ease in assembling. However, it achieved low flexibility level due to required operator to move the tiles which can be optimized in future researches by application of linear actuators.

Indicator		Value	Indicator		Value
I1	Fabrication & assembling cost	37,69€/m^2	**I8**	Recyclability	97%
I2	Maintenance cost	3€/m^2/a	**I9**	Reusability	89%
I3	Dismantling cost	1€/m^2/a	**I10**	Fabrication easiness	9/10
I4	Embodied energy	104.41 kWh/m^2	**I11**	Flexibility	6/10
I5	Embodied carbon	19.46 kgCO_2/m^2	**I12**	Ventilation performance	5/10
I6	Energy saving	35%	**I13**	Lighting performance	7/10
I7	Energy conversion efficiency	-1.2%	**I14**	Reusability	8/10

Table 13. Main architectural features of proposed façade based on developed requirements tree.

The global sustainability index GS_k along with the partial satisfaction indexes for the proposed façade are presented in Table 14. As expected, the economic index for the proposed façade shifted considerably and stayed at the highest level. Mostly that is due to required production materials, which also has environmental factors.

Alternative	**SI_{R1k}**	**SI_{R2k}**	**SI_{R3k}**	**GS_k**
Proposed façade technology	1.00	0.88	0.69	0.83

Table 14. Resulting sustainability indexes for proposed alternative.

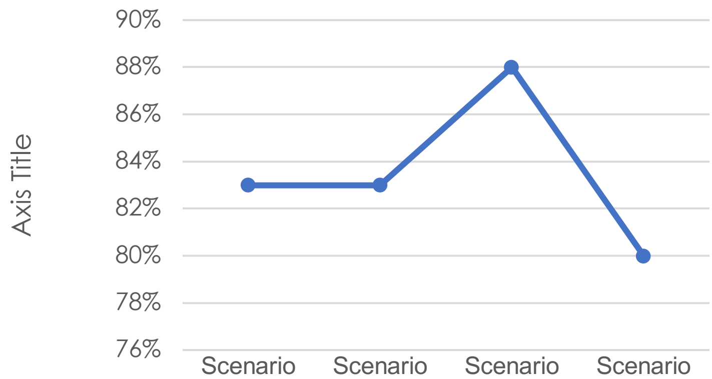
Legend: Sustainability Index for economic requirements (SI_{R1K}), Sustainability Index for environmental requirements (SI_{R2K}), Sustainability Index for social requirements (SI_{R3K}), Global Sustainability (GS_k).

The last step aims to analyze the sensitivity of the results. In this sense, the new facade system has been assessed through changing the assigned weights for requirements in four different scenarios. Table 15 illustrates the input scenarios. Scenario E1 corresponds to the economic, environmental and social weights originally proposed by the experts in previously developed MIVES tool. Alternatively, scenario E2 considers a balanced distribution of weights, in which the requirements have the same weight. In scenario E3, the final decision has been obtained with the greater weight placed on the economic requirement and finally, in scenario E4, the environmental requirement was assigned a greater weight. Finally, the robustness of this study is achieved when each requirement for each scenario for proposed façade does not have a variation more than ±10% from research project scenarios.

Sustainability requirement	Panelist scenario (E1)	Neutral scenario (E2)	Economically biased scenario (E3)	Environmentally biased scenario (E4)
Economic	34%	33.33%	50%	30%
Environmental	36%	33.33%	30%	50%
Social	30%	33.33%	20%	20%

Table 15. Variable scenarios used for sensitivity analyses.

The sensitivity analyses in three different scenarios and the proposed weights from the experts in MIVES provided more evidence for these results. In order to study the influence of MIVES on the ranking of the proposed façade, this study has compared through different weight assignments for each requirement.



	Scenario MIVES	Scenario E1	Scenario E2	Scenario E3	Variation E1 to E2	Variation E1 to E3	Variation E1 to E4
Proposal	83%	83%	88%	80%	0%	5%	-3%

Table 16. Sensitivity analysis and variations of each scenario.

As presented in Table 16, in all scenarios, the new proposed façade technology has performed great as anticipated and has placed in highest sustainability satisfaction. The variations are not significant and confirm the robustness for the approach used in this research project.

To sum up, this new proposal presents a new low-cost façade system which will be able to provide better comfort to our buildings' inhabitants and less emissions and energy consumption by rehabilitating their façades while reusing the sanitary waste from COVID-19 pandemic. This reuse implies recollection in health and educational centers that provides awareness for future generations.

In doing so, this proposal starts a new movement towards new circular façades for the future of our architecture in a better Society.

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ANNEXES

Annex A. The abbreviations used in the text.

Abbreviations	Relevant values
PET	Polyethylene Terephthalate
PP	Polypropylene
TTI	Time to Ignition
VAWT	Vertical Axis Wind Turbine
LCC	Life Cycle Assessment
LCA	Life Cost Assessment
MCDM	Multi-Criteria Decision Making
LED	Light Emitting Diodes
TiO_2	Titanium Dioxide
WWR	Window-to-Wall Ratio
MSW	Municipal Solid Waste
cDA	Continuous Daylight Autonomy
sDA	Spatial Daylight Autonomy

Annex B. The designed poster for collection of waste materials which has been shared in social medias.

Annex C. Requirements tree of the previously developed MIVES assessment tool.