



OPEN Life cycle assessment of a luxury fashion brand's HPP event booth in the context of circular economy

Duan Wu¹✉, Zixin Ren¹, Haoyue Lei^{1,2} & Shijian Zhao^{1,2}

This paper investigates the impact of High-Profile Promotions (HPPs), specifically luxury beauty and aroma booths, on environmental sustainability. While most prior research on similar pop-up installations has focused on their commercial value, this study approaches the topic from an environmental sustainability perspective. It quantifies the environmental impact of HPPs, transitioning from qualitative assessments to quantitative analysis, and explores potential environmental protection strategies for brands when planning HPP events, particularly regarding the selection of construction materials. The methodology employed in this study integrates Life Cycle Assessment, Eco-Indicator 99 (EI 99), and Comparative Study approaches. This comprehensive analysis, exemplified through a case study of an internationally renowned aroma brand, investigates the full life cycle of an HPP event booth. The study meticulously deconstructs the components and materials involved, quantifying their environmental impacts using the EI99 index. These environmental impact assessments are subsequently compared to those of conventional massive buildings, enabling a robust evaluation of the relative sustainability and resource efficiency of the HPP structures. Through calculation and analysis, this study reveals that the daily carbon emissions of different HPP options were found to range from 162 to 1308 times that of a conventional massive building, and varying material choices can potentially reduce HPPs' daily carbon emissions by approximately 73%. This underscores the critical role of material selection in mitigating environmental impact within the context of pop-up retail. Notably, furniture components, particularly cabinets, emerge as pivotal areas where carbon footprint reduction efforts can be most effectively concentrated. Finally, this research offers valuable insights and practical guidance for environmentally conscious brands in the design and implementation of pop-up retail strategies. By incorporating these findings, brands can align their operations with principles of sustainability and social responsibility, promoting a more balanced and sustainable impact on society.

As e-commerce growth continues to outpace that of brick-and-mortar retail, temporary retail spaces, also known as pop-up shops, are becoming a crucial promotional strategy, especially for online retailers and service providers¹. In this context, many brands are focusing on creating immersive experiences in offline spaces, with new retail pop-up stores becoming one of the most effective ways to engage young consumers. In 2020, the turnover of China's pop-up store industry exceeded 80 billion yuan, with approximately 9.6 million pop-up events occurring².

Pop-ups, defined as short-term, spontaneous business activities, involve brands renting smaller spaces for brief periods to quickly capture consumer interest in a product or service. In China, 65% of pop-up stores operate for less than 10 days³. This business model offers substantial benefits.

According to a report by Cushman and Wakefield⁴, pop-up store rents are typically 30–40% lower than those of traditional retail stores, while their sales are 20–30% higher. Furthermore, pop-up stores are generally rented for a few weeks to a few months, allowing them to adapt quickly to market conditions, unlike traditional retail stores, which are often leased for several years. A study by RET Reynolds found that pop-up stores are highly cost-effective for attracting foot traffic and generating sales revenue³. In the current Chinese market, pop-up stores match IP-based exhibitions in customer attraction and surpass them in revenue generation. Compared to general catering, fast fashion, and cinemas, pop-up stores excel in drawing customers as in Fig. 1.

Pop-ups offer freshness and experiential value to consumers and significant commercial benefits to brands. However, their short duration, thematic focus, and irregular venues raise several environmental and sustainability concerns. This study aims to assess the environmental impact of pop-up spaces quantitatively, identify design

¹Tongji University College of Design and Innovation, Shanghai 200092, China. ²Haoyue Lei and Shijian Zhao have contributed equally to this work. ✉email: wudian@tongji.edu.cn

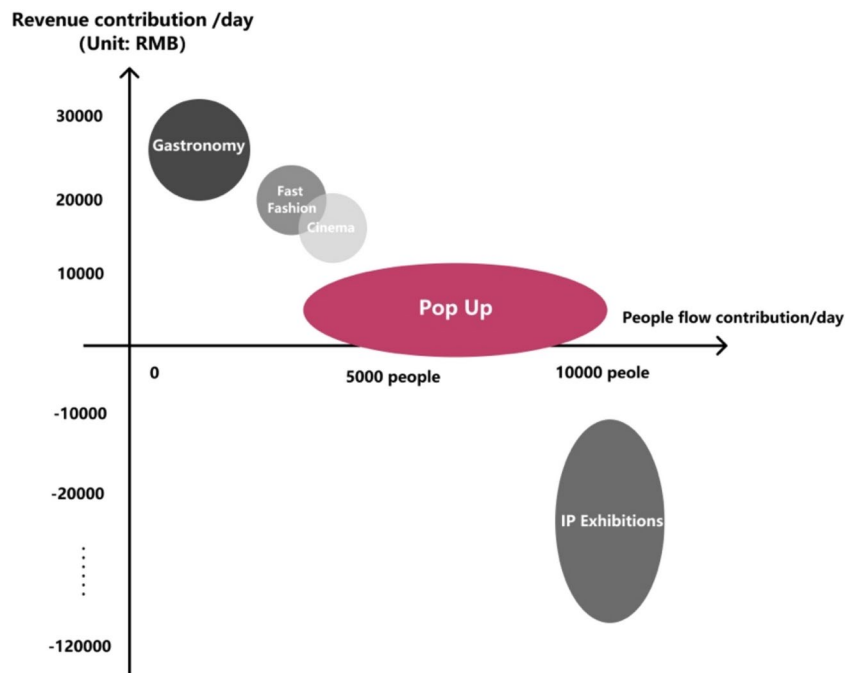


Fig. 1. The performance of pop-up stores and other shopping center formats in terms of customer aggregation. (Source from Flash Space and RET Reynolds China Commercial Real Estate Research Centre).



Fig. 2. Typical HPP event booth.

opportunities, and propose improvement strategies. The research focuses on High-Profile Promotions (HPPs), a specific type of pop-up. By collaborating with an internationally renowned perfumery brand, referred to as D Brand, field research was conducted at the brand's processing plant and end-of-life facility for HPP event booths.

HPPs, used predominantly by high-end fashion and luxury brands (e.g., Prada, LVMH), are short-term promotional events designed to boost brand visibility and attract targeted customer groups during important occasions. Compared to pop-up activities of ordinary or start-up brands, HPPs as Fig. 2 showed are more temporary, require higher investment, and are geared toward maximizing commercial value.

For D Brand, HPPs are week-long events held hundreds of times a year across different regions, typically featuring aesthetically appealing, semi-open booths with strong circulation, measuring approximately 9 m × 15 m × 3 m. This study will analyze the materials used in constructing a typical HPP event booth from a product life cycle perspective to provide design insights and identify opportunities for sustainable improvement.

Materials and methods

Ethics statement

All protocols in this study were approved by the Tongji University Science and Technology Ethics Committee, Shanghai, China (permit number: TJDXSR021). All methods were carried out in strict accordance with relevant guidelines and regulations.

In addition, informed consent was obtained from all participants involved in the study and all participants signed informed consent forms. As all participants were over the age of 16, consent was provided directly by the participants.

Description of information sources

The project team employed non-participant observation and expert interviews for this study. Field research was conducted at the construction and scrapping facilities of the HPP booth to observe the production and processing activities in situ. Interviews were also conducted with brand managers and frontline manufacturing staff to gain a comprehensive understanding of the entire lifecycle of HPP production, processing, and deployment⁵ as in Fig. 3.

Life cycle assessment (LCA)

This study employs the Life Cycle Assessment (LCA) methodology, a quantitative approach that collects and analyzes data to quantify the environmental impacts of a product or system throughout its entire lifecycle,

User research record & summary

What do we hear?

- 4 Pulpboard is environmentally friendly and sustainable compared to wood and has been used to a certain extent in Singapore. However, there is a lack of hardness in the pulp board processed by domestic technology, and it is expensive to import
- 5 The worker said there was a detailed coding system and electronic filing and that anything you needed could be found after searching in the files
- 6 All scrap materials will have a fixed cooperative third-party for recycling.
- 7 HPP's design plan is mainly developed by the foreign brand headquarters, then issued guide book, the Chinese team according to the actual situation in China to modify the details, repeatedly finalize the plan before the implementation of the landing.
- 8 When talking about sustainability-related measures, the factory cited the use of sustainable materials in Southeast Asia and the United States, and the use of photovoltaic power generation in China, but the factory doesn't track the waste in its own factory

What do we think?

- 1 If the end-of-life rate is inevitable (as it is necessary for luxury brands to consume a certain amount of resources to renew their counter image to match the effect of the campaign), is it possible to improve the craftsmanship in the use of raw materials.
- 2 What exactly is the recycling process like? If it is sold, how much is the cost feedback? What happens to the recycled material, is it actually recycled or is it simply landfilled as waste?
- 3 Is acrylic an environmentally friendly material? How reusable is it? What are its material properties? What can be used as a substitute? What are the reasons for its high frequency use? More in-depth research is needed...

What do we wanna know?

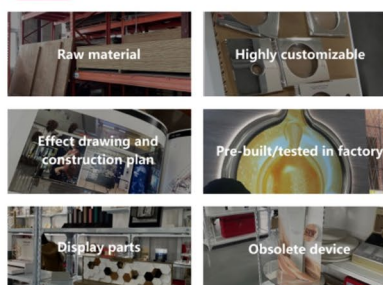
- 2 How much freedom does the Chinese team have in terms of design? How much design adjustment is acceptable to the head office?
- 2 Which type of components can be reused?

What do we see?

- 1 The counters are exquisitely crafted and expensive, but have a lifespan of only 1-2 weeks and a high end-of-life rate (a few counters or items will be reused within the brand)
- 2 The factory has a wide range of acrylics, extra thick, mirrored and so on. This material seems to be very popular with the beauty industry.
- 3 The warehouse looks so messy.

Field research on HPP booth's production factory

SEE



FACT

Material Selection

- Use more environmentally friendly/reusable pulp boards instead of wood boards
- The production of domestic pulp plates is small and the price is high, mainly relying on imports
- Use water-based paint instead of oil-based paint

Design

- Use modular design to facilitate material reuse, eg. Mirrors, chairs, lamps in the try-on area
- Using light box + tin foil and aluminum foil can reduce the number of lamp tubes

Reuse

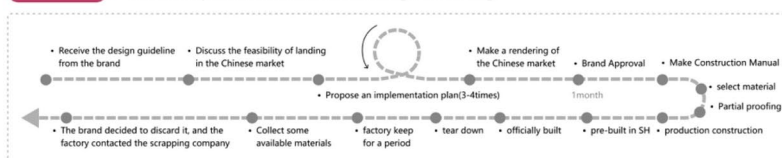
- Reusable components: lamps, chairs, warehouse structures
- The structure of the display frame has changed a lot, and the reuse rate is low
- Due to the change of brand image, there will be major changes in the exhibition

Waste disposal

- The main categories of waste processed by third-party scrap companies: acrylic, wood structure, glass, metal
- Due to color difference and quality cannot be guaranteed, scrap material will not be recycled
- Update frequency: 1-2 weeks for flash devices, 1-2 years for permanent devices

PROCESS

The whole process from showcase design to landing



REFLECTION

1. Brand positioning of luxury goods (high quality texture & visual effect) VS low quality of recycled materials

- In order to satisfy the public's awareness of brand positioning, luxury brands create a sense of luxury through visual effects
- It is difficult to guarantee the quality and effect of material recycling
- Booth materials of different brands are highly customized and difficult to use universally

- Public awareness of luxury brands? Does the advanced visual effect of the booth affect the consumption behavior of the public?
- How do scrap companies deal with waste materials now?
- Apart from dismantling and reusing materials, what other ways can be used for abandoned booths? eg: Does the existing beauty store (Xi Ran, Colorist) have any demand for out-of-season booths?

2. Implementation cost vs profit of sustainable concept

- The cost of material recycling and reuse is high, so brands and factories lack strong execution motivation
- The plan and cost are mainly controlled by the brand side, and the third-party factory is the plan executor, lacking the right to speak
- The implantation of sustainable concepts will break the existing stable production process

- What sustainable options are there besides material recycling?
- For sustainable implementation, it needs to be initiated by the brand side, and the factory should cooperate
- Can the later material processing scheme be added to the earlier scheme design?

3. Material thinking already have

- There have been cases of using pulp board instead of wood structure, but limited to manufacturing costs
- Water-based paint can also replace part of the paint, but the effect is slightly poor and cannot be completely replaced

- The physical props designed for shooting include: background, decoration, exhibition plate, lamps (model, color temperature and brightness are different, but can be reused), Frame

Fig. 3. Field research interview transcripts.

including resource consumption, energy use, and waste generation. LCA is extensively used in industrial processes to evaluate the environmental footprint of products⁶. In this study, LCA provides a scientific basis by quantifying the lifecycle impacts of the HPP booth and its components, identifying potential environmental impacts, and highlighting key opportunities for improvement.

Eco-Indicator 99 (EI 99)⁷

To enhance the specificity of the data, this study utilizes the Eco-Indicator 99 (EI99) method alongside LCA calculations. EI99 is a damage-oriented methodology that assesses the impact of emissions, extractions, and land use on human health, ecosystem quality, and resource depletion. These impacts are consolidated into a single score⁸. EI99 offers standard eco-indicator values for commonly used materials at various stages of production, transportation, use, and disposal, facilitating the assessment of the product system's environmental performance. The calculation methodology for these standard eco-indicator values is detailed in the EI99 guidelines and is not elaborated upon in this study. In the EI99 method, the unit of all indicator values is the Point (Pt), where 1 Pt represents one-thousandth of the annual environmental load of an average European resident. Based on the latest data from the International Energy Agency (IEA)⁹, which reports per capita carbon dioxide emissions in Europe in 2021 as 5.37 t CO₂e, 1 Pt is approximately equal to 5.37 tonnes of CO₂eq. This study converts the results into an average daily carbon emissions value for more intuitive data analysis.

Comparative study

The main objective is to assess differences and impacts between variables comprehensively. In this research, we compare the environmental impact of different HPP material options. Given that different HPP events feature diverse design styles and that designers and engineers select varying materials and quantities during construction, the calculation process involves significant estimation, leading to inevitable errors. The research team identified the components and common material choices for a typical HPP. The specific estimation logic for each item is detailed in the accompanying table.

Comparative Studies help with providing insights into the effectiveness, efficiency, and sustainability of various options. By examining multiple scenarios or alternatives, we can inform decision-making processes, design processes and strategic planning aimed at minimizing environmental impact and maximizing resource efficiency.

Findings

Life cycle assessment of HPP for Brand D

The lifecycle of retail stores can be divided into three stages: Creation, Provision, and End-of-Life. The first stage encompasses activities such as locating specific premises, conceptualizing, designing, and constructing the store—essentially, all pre-service activities. The second stage involves the actual provision of the service. The third stage includes activities required to terminate the service, such as dismantling and waste treatment of redundant materials. Based on this framework, this study explores the lifecycle of HPPs in more detail, using Shanghai, China, as a case study. Following three offline field studies and direct communication with the brand, the research team identified the overall organizational process for an HPP as follows in Fig. 4.

- Design Guideline Reception

The subsidiary first receives design guidelines from the parent company, which include the event theme, cycle, and design renderings for the HPP event. The subsidiary then discusses the feasibility of the HPP program in

Current Life Cycle Of HPP (of Brand D)

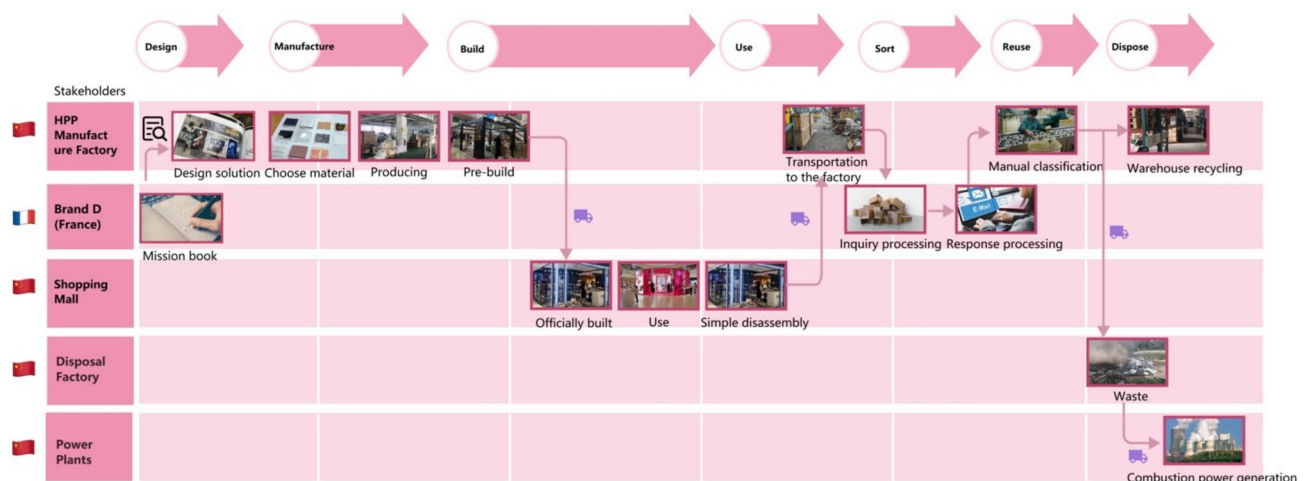


Fig. 4. Full process grooming for HPP organizations.

the Chinese market with senior management, proposes an execution plan, and produces renderings tailored to the Chinese market.

- Feedback and Approval

The Chinese design team sends the design back to the parent company for approval. Once approved, the team collaborates with partner factories for production.

- Booth Construction

Construction involves pre-assembly and final assembly. The factory first completes the entire HPP build-up on-site, confirms the design, dismantles the parts, and transports them to the event location for final assembly.

- Event Execution

During the event, Brand D's HPP showcases themed displays, offers experiential make-up trials, and organizes interactive sessions with consumers. These activities typically cause minimal wear and tear on the installations.

- Booth Dismantling and Scrapping

After the event, the showroom enters the dismantling phase. The factory retains the dismantled components for a period, sorts reusable materials, and provides a scrapping recommendation for the remaining materials to Brand D. If authorized, the factory contacts a scrapping company to dispose of the materials.

Typical HPP components of Brand D

To identify design opportunities, the researchers categorized the components, materials, and furniture of a typical Brand D HPP booth into three categories: non-recyclable, recyclable until functionality is lost, and reusable. In Table 1, the team found that Brand D currently recycles only 14–34% of materials directly, with approximately 20% not entering the recycling process after a campaign lasting about 1 week.

The research team further analyzed the components, materials, and processes involved, summarizing their findings in Fig. 5. For example, PVC synthetic flooring is most commonly used due to its cost-effectiveness and ease of assembly, but it is typically discarded after the event. Some HPPs opt for floorless setups or solid wood flooring, which are also discarded post-event.

A typical HPP for Brand D consists of structures, furniture, and electrical equipment. Vanity chairs, tables, and light fixtures are often reused as they are not strongly theme-specific. However, walls, floors, art installations, and facing materials are usually discarded after a single event due to customization requirements, although most of these materials are recyclable. Brands often sacrifice material recycling to protect intellectual property rights.

Frames, especially metal ones, can ideally be recycled. Large frames made of unit frames or welded steel bars can be dismantled and reassembled for future events. Modularity is thus an effective and sustainable solution. However, recent HPP events by Brand D revealed that frames vary significantly, limiting their practical reuse. Consequently, frames are included in the recycling or end-of-life process alongside other materials.

Cabinets, being complex and material-intensive, are typically made from a combination of metal, glass, leather, chipboard, plywood, and pressboard. The variety of materials allows for selective recycling, but Brand D often prioritizes higher quality over recycling efficiency. Whether cabinets are reused depends on brand authorization, but field research indicates that time constraints usually prevent reuse. Therefore, cabinets are generally included in the end-of-life process in the subsequent calculations.

Typical HPP metric calculation for Brand D

To provide a clearer conclusion, the team estimated the quantities of various materials used in the HPP and calculated their environmental indices. First, the functional units for the main body of the calculation were defined according to the requirements of the EI99 methodology. Then, the specific indices for the materials involved in each part of the component were calculated individually. All the individual results were summed, and finally, the results were compared with the indicators for massive buildings of the same volume as provided in the EI99 manual.

The primary function of the HPP is to facilitate high-profile promotions for the brand. To achieve this, the team set the functional unit of Brand D's HPP to be operational for 12 h a day (10 a.m.–10 p.m.), which is the average opening time of shopping malls in Shanghai) continuously for 1 week. The estimated space size of a typical HPP is 9 m × 15 m × 3 m. Through researching several HPP events of Brand D from January 2023 to May 2024, it was found that the events were held in three shopping malls located in central Shanghai, with the construction and scrapping factories about 20 km away. Therefore, the material transportation distance was estimated to be 80 km, including two round trips with an empty truck for each trip.

It is important to note that the calculation process only considers the spatial materials needed to build the HPP event booth, excluding products for sale or giveaways, as well as environmental impacts generated by people during the building or operation process.

Based on the analysis of HPP's constituent components, the research team focused on calculations for the floor, walls, frame (including off-wall and in-wall frames), cabinets, furniture, electrical equipment, art installations, and facing materials, with all decorative materials unified in the facing section. The specific calculation process is shown in Fig. 6, and more detailed calculations can be found in the Appendix (Table 2).

Sector of item	Name of item	Frequency of Use Before Recycling	Materials Potentially Involved	Materials recoverability assessment	Fatures and functions of material
Structure	Floor	× Rarely reused, they will be dismantled and discarded after the event	No floor	✓ Recycle several times before landfill/incineration	The HPP flooring is intended to protect the site's original surface. If the original surface is durable and requires minimal protection, such as concrete or soil, the flooring may be left in place. However, such cases are rare
			PVC artificial flooring	✓ Recycle several times before landfill/incineration	Cheap and easy to assemble
			Solid wood flooring (Usually in hardwoods such as oak and walnut)	✓ Recycle several times before landfill/incineration	Expensive, reflecting the class of the brand
	Wall	× Rarely reused, they will be dismantled and discarded after the event	Metal wall keel (usually light steel keel, made of aluminium alloy sheet or cold rolled galvanised sheet)	✓ Recycle	Cheap, lightweight and load-bearing as a wall support structure
			Wooden wall keel	✓ Recycle several times before landfill/incineration	As a wall support structure, cheap, lightweight, with average load-bearing capacity
			Wooden wall coverings, most commonly made of chipboard	✓ Recycle several times before landfill/incineration	Non-load-bearing veneer panels
			Putty powder	× Straight to the landfill/incineration	Putty powder, known for being cheap, lightweight, and decorative, is one of the most widely used materials in the decoration industry. It is primarily composed of heavy calcium, light calcium, wollastonite, cellulose, water-soluble starch, and titanium dioxide. These components are added to a mixer and blended thoroughly until the mixture meets the appropriate standards
	Off-wall frame	? The entire frame is rarely reused, while the individual bars will be repurposed	Stainless steel bars with baking paint of Polyester, epoxy resin, polyurethane (the most common occasion)	✓ Recycle	In the case of a frame structure with a large span, it will act as an expensive load-bearing structure
			Aluminium alloy + painted (the most common occasion)	✓ Recycle	Light , and easy to assemble
	In-wall frame	? The entire frame is rarely reused, while the individual bars will be repurposed	Lightweight steel keel (the most common occasion)	✓ Recycle	Made from steel, a metallic material that can be recycled and reused many times over
			Pine wall keel (the most common occasion)	✓ Recycle	Biodegradable
Furniture	Product display stand	×Hardly ever use it again.(but in the case of the insert form—where the spacing can be adjusted—it may be used several times.)	Acrylic	✓ Recycle several times before landfill/incineration	Carrying a small amount of cosmetic load-bearing
	Cabinet	? Whether to reuse depends mainly on the brand idea (The better quality cabinets will be used twice. If the brand decides to recycle, in most cases will be disassembled by a dedicated company will be left with the panels, the external finish will be stripped and sanded off (generated pollution))	Metal	✓ Recycle Non-renewable	Non-load-bearing finish panels, mainly stainless steel, brass and aluminum
			Mirror Glass	✓ Recycle	Non-load-bearing veneer panels
			Transparent glass	✓ Recycle	Non-load-bearing veneer panels
			Leather	✓ Recycle several times before landfill/incineration	Non-load-bearing veneer panels
			Chipboard (Made from recycled wood products)	✓ Recycle several times before landfill/incineration	Non-load-bearing veneer panels
			Plywood (Made from recycled wood products)	✓ Recycle several times before landfill/incineration	Load-bearing structural panels Plywood materials have the advantages of light weight, high strength and durability, and are relatively inexpensive to produce
			Pressed plywood	✓ Recycle several times before landfill/incineration	Wooden skeleton A kind of board made of multi-layer thin wood or other materials after gluing and compression, with good strength and stability
	Chairs	✓ High probability of being reused multiple times	Mix materials	Reuse	
		✓ High probability of being reused multiple times	Mix materials	Reuse	
Continued					

Sector of item	Name of item	Frequency of Use Before Recycling	Materials Potentially Involved	Materials recoverability assessment	Fatures and functions of material
Electrical Equipment	Track spotlights Bulbs multi media equipment	✓ High probability of being reused multiple times	Metal shell (Aluminum) + COB lens (light source) or LED	Reuse	
Art Installation	Mix materials	✗ Hardly ever use it again	General materials: aluminum, acrylic, led light source etc	✗ Straight to disposed	To appear as a device of attraction; Easy to shape, brilliant effect (decorative oriented)
Facing Material	Mix materials	✗ Hardly ever use it again	General materials: paper, cardboard packaging, wood paneling, glass etc	✗ Straight to the landfill/ incineration	For decoration

Table 1. Collation of typical HPP material properties for Brand D.

• Floor

HPP mainly uses PVC material for flooring. PVC particles have an equal probability of entering the recycling and landfill processes, so the waste link calculates values for both disposal methods, each accounting for half of the total amount.

• Wall

Given the high circulation characteristic of the HPP booth, it is preset to have only two vertical walls and a top surface, with the other two surfaces supported by frames.

• Frame

The frame consists of two parts: the inside wall frame and the outside wall frame. The mainstream choice of materials for the outside wall frame includes stainless steel and aluminum alloy, which serve as substitutes for each other. For the in-wall frame, the choice is between lightweight steel keel and pine wood keel.

• Furniture

Furniture includes cabinets (wood paneling), product displays (acrylic), and tables and chairs. Since tables and chairs are reused furniture with a longer lifecycle than the HPP, only the data generated from transportation are calculated.

• Electrical equipment

Electrical equipment is included in the calculations as part of the total environmental impact.

• Art installation

Art installations present the largest error margin due to varying inputs for each event. Therefore, the calculation uses the indicator for Metal construction building in the EI99 indicator and estimates the installation volume to be 4m³.

• Facing material

Facing materials are challenging to estimate due to the wide variety of choices. The team averaged the EI99 indicators of materials such as paper, cardboard, wood panels, glass, PVC, PP, iron, aluminum, and copper, and estimated the total weight of all finishes to be 20 kg.

Discussion

Comparative analysis of HPP and permanent building carbon emissions

After the calculations, the research team gained a preliminary understanding of the environmental impacts of each component. To better visualize the data, they compared the results with the environmental impact of a massive building of the same volume (405 m³) from the EI99 methodology. A massive building of this volume would generate an environmental impact of around 607,500 Pt, equivalent to approximately 3,252,275 tons of CO₂ emissions, assuming a lifespan of 10 years. The average daily carbon emissions for such a building are approximately 893.8 tons.

To provide a comprehensive comparison and better understand the potential environmental impacts of different material choices and configurations, the research team evaluated three distinct options for the HPP event booth. The EI99 guidelines do not specify whether a massive building includes multimedia, furniture, and fixtures in its environmental impact calculation. Therefore, these components are not included in Options 1 and 2 for the HPP but are added in Option 3.

The difference between Options 1 and 2 is that Option 1 uses stainless steel and lightweight steel keel for the off-wall and in-wall frames, while Option 2 uses aluminum and pine wood keel. This comparison allows us to see

Typical HPP booth model (of Brand D)

Component

- Floor
- Wall
- Off-wall frame
- In-wall frame
- Furniture
- Electrical Equipment
- Art Installations
- Facing Material

Definition

Dimension:
9m*15m*3m

Specificities:
Semi-open space with high circulation

Function Unit:
Open 12 hours a day (10am–10pm, which is the average opening time of shopping malls in Shanghai) for one week.

Location



Materials

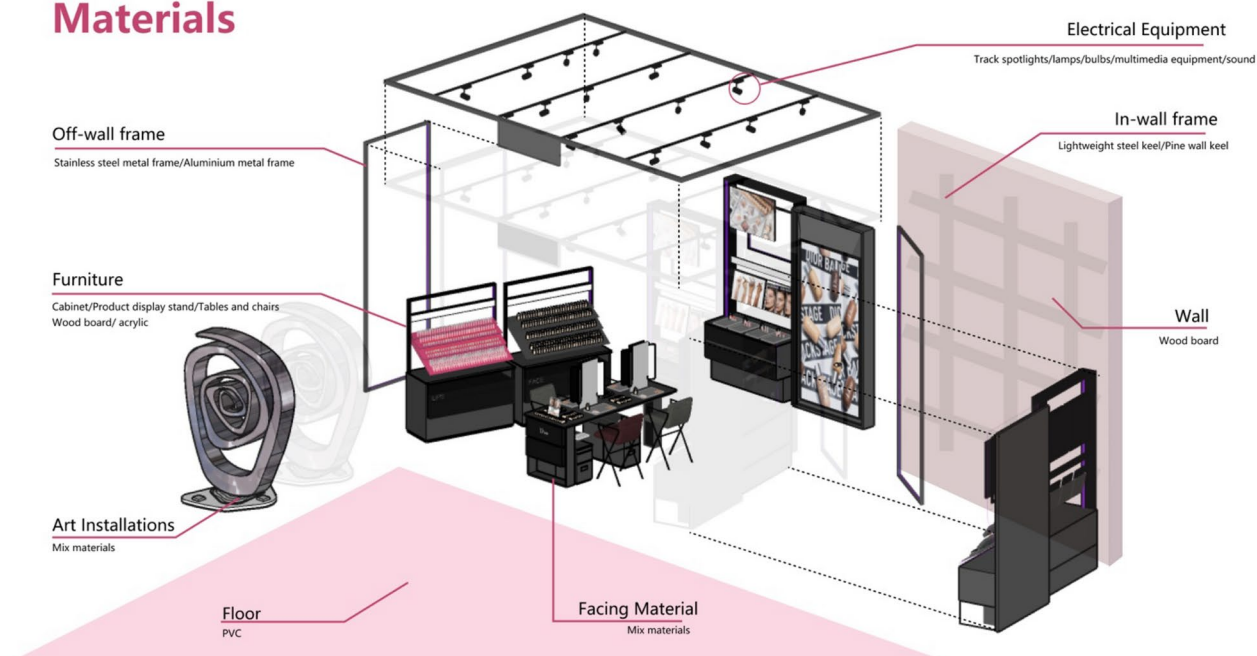


Fig. 5. Compilation of Required Components for a Typical HPP for Brand D.

how the choice of materials with different environmental impacts influences the overall carbon footprint. Option 3 includes multimedia, furniture, and art installations, i.e., the maximum values for all calculations, to assess the comprehensive impact when all possible components are considered.

The environmental impact data for HPP, excluding electrical equipment, furniture, and art installations, ranges between 188,539 Pt and 689,353 Pt. Given that the impact for a massive building is 607,500 Pt, the calculation is relatively reasonable in Table 3.

This analysis led the research team to conclude the following findings.

Short lifespan increases huge environmental impact

Despite the material choices making HPPs appear environmentally friendly compared to conventional massive buildings, the short lifespan of HPPs (normally 7 days to half a month) results in a much higher average daily carbon emission index.

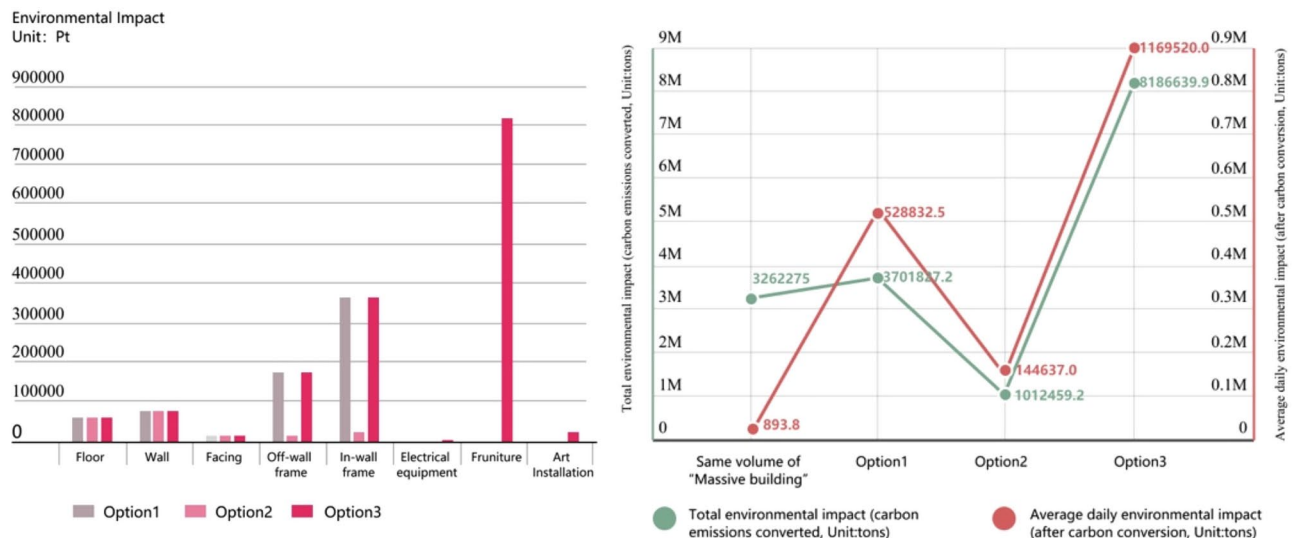


Fig. 6. Data visualization of calculation results.

Floor	Product: PVC flooring				
	Pre-calculation:				
	Area: 9 m * 15 m = 135 m ²				
	Volume: 135 m ² × 0.002 m = 0.27 m ³				
	The estimated density of PVC is 1.4 g/cm ³ (1400 kg/m ³)				
	PVC particle volume = floor volume × PVC density				
	PVC particle volume = 0.27 m ³ × 1400 kg/m ³				
	PVC particle volume = 378 kg				
	Conclusion: Approximately 378 kg of PVC pellets are required to lay 135 m ² of PVC flooring				
	Item	Category	Quantity	Indicator	Result
	Production	PVC (flexible)	378 kg	240	90,720
	Processing	Calendering PVC foil	378 kg	3.7	1398.6
	Transport	Truck 16 t	0.0038 t * 20 km * 4	34	10.336
	Waste treatment	Landfill PVC	189 kg(50%)	2.8	529.2
		Recycling PVC	189 kg(50%)	- 170	- 32,130
			Total		60,528.136
	Description of the situation:				
	1. Transportation for HPP erection and dismantling mainly involves 2 round trips from the factory to the mall, which is roughly 20 km, so the total transportation distance is estimated to be 80 km				
	2. The transportation of HPP erection and dismantling mainly uses trucks with the same loading capacity, and in rare cases, vans will be used to load the dismantled HPPs (because it will increase the dismantling time in the shopping malls a lot, which will increase the cost)				
	3. It is understood that the trucks used for transportation are 9.6 m vans with a loading capacity of about 12–23 t, so a 16 t truck is selected for calculation in the EI99 listings				
	4. According to the staff of HPP's scrap plant, the treatment of PVC in the market is roughly recycling and landfill, and the probability is 1:1. Recycling mainly refers to re-breaking PVC into particles for recycling, while the more toxic PVC will be made landfillable by adding chemical contents. Therefore, in the calculation, it is estimated that 50% of each PVC goes to recycling and landfill respectively				

Table 2. Calculation results of PVC flooring.

By calculating the average daily carbon emissions, we can compare the daily environmental impact of HPP with the regular emissions of permanent buildings, yielding intuitive data comparisons and insights for our study conclusions. Based on the data tracked from Brand D, the usage cycle of HPP ranges from 7 to 14 days; we use a median value of 10 days as the basis for our calculations. According to the previous calculations, the

Comparative analysis of data	Total							
	Reference value		Option 1	Value	Option 2	Value	Option 3	Value
	Massive building index: 1500/m ³ Calculation: 1500/m ³ × 405m ³ (Standard HPP volume)	Floor	✓	60,528.14	✓	60,528.14	✓	60,528.14
		Wall	✓	77,724.36	✓	77,724.36	✓	77,724.36
		Facing	✓	11,708.4+	✓	11,708.4+	✓	11,708.4+
		Off-wall frame	Stainless steel	174,679.08	Aluminium	15,993.72	Stainless steel	174,679.08
		In-wall frame	Lightweight steel keel	364,723.32	Pine wood keel	22,585.264	Lightweight steel keel	364,723.32
		Electrical equipment	×	0	×	0	✓	1160.16
		Furniture	×	0	×	0	✓	817,020.48–
		Art installation	×	0	×	0	✓	16,970
	607500Pt	Total		689,353.3+		188,539.884+		≈1,524,513.94
Conversion to CO ₂ eq (unit:ton)	3,262,275			3,701,827.2+		1,012,459.2+		≈8,186,639.9
Average daily carbon emissions	893.8			528,832.5+		144,637+		≈1,169,520

Table 3. Summary of calculations.

average daily carbon emissions for a permanent building are 893.8 tons. In contrast, the values for HPP are approximately 528,832.5 tons for Option 1, 144,637 tons for Option 2, and 1,169,520 tons for Option 3, which are 592 times, 162 times, and 1,308 times that of a conventional massive building, respectively. This clearly demonstrates the substantial environmental impact of HPP.

Material choices affect carbon footprint

The team observed that different material choices for the in-wall and off-wall frames significantly impact the overall environmental footprint. Stainless steel and lightweight steel keel have much higher environmental impacts than aluminum and pine wood keel.

When we applied the same calculation method and compared HPP option 1 and option 2 with different material choices, we found their daily carbon emissions differed by 3.65 times. This suggests that appropriate material selection could help HPP reduce its daily carbon emissions by approximately 73%.

Designers and engineers should consider materials with lower environmental impacts at the outset of the design process. The EI99 manual lists materials with low environmental impact indices, such as recycled aluminum, electrical steel, glass, cardboard, cement, sand, and wood panels. Using recycled materials can even result in negative environmental impact indices, contributing to carbon reduction (Fig. 7).

Findings on furniture-related carbon emissions

The analysis reveals that furniture, particularly cabinets, contributes significantly to carbon emissions among all HPP components. This notable impact may be attributed to the predominant use of wooden boards in cabinet construction. The research team posits that, for short-term activities like HPP, it is feasible to transition the storage function from wooden cabinets to lighter, more environmentally friendly materials such as recycled cardboard. Additionally, redesigning cabinets for reuse in multiple events could further mitigate their environmental footprint.

Through interviews and discussions, the research team discovered that Brand D has attempted to integrate sustainability into the entire HPP process and aims to reuse associated consumables. However, several challenges hinder the realization of this goal:

- Conflicts between Premium Brand Positioning and Recycled Materials:

Brands often strive for high-quality texture and visual appeal, which recycled materials may not consistently provide. The high degree of customization in HPP booth materials further complicates the standardization of recycled components.

- Lack of Motivation to Recycle Materials:

The current high costs of material recycling and reuse deter both factories and brands from prioritizing these practices. Partner factories, responsible for executing brand programs, also have limited influence in the decision-making process.

- Insufficient Demonstration of Sustainable Value:

Commercial brands seek visible returns on their investment in sustainability, whether financial or in terms of brand recognition. Merely recycling materials can risk diminishing the brand's perceived quality without clearly showcasing its commitment to sustainability, thus reducing the incentive for recycling initiatives.

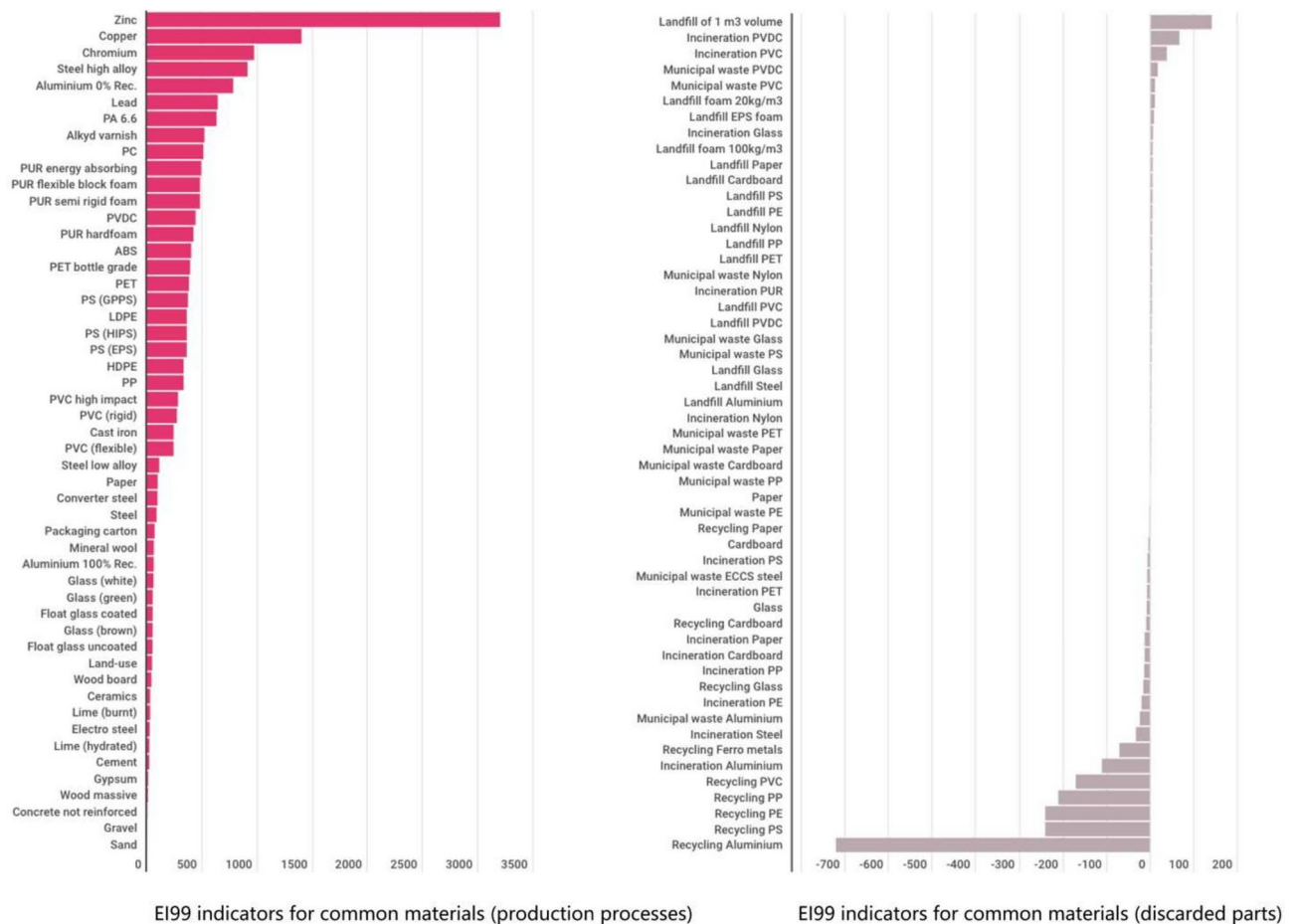


Fig. 7. Comparison of Ei99 indices for common materials for production and waste mitigation.

System design opportunities in the HPP process

By examining Brand D's HPP organizational structure, operation cycle, component materials, and recycling methods, the research team identified several design opportunities, confirmed through interviews and branding analyses:

- **Internal Component Recycling and Registry:**

Brand D has adopted the practice of reusing certain components until they are completely unusable. Creating a registry to document material properties, reuse frequency, and application contexts could facilitate the selection and use of materials in future HPP campaigns.

- **External Component Recycling and Second-Hand Market Development:**

To allow HPP components to enter the second-hand market, Brand D must ensure these items are unbranded to protect intellectual property. Thus, brands could design easily removable brand logos to promote external reuse and extend material lifecycles.

- **Digital Maintenance and Repair Instructions:**

Brand D's global operations require the decentralization of concepts and designs. Implementing an online smart warehouse management system with digital repair instructions from the parent company could empower local subsidiaries to maintain and reuse products more efficiently.

- **Redesign and Enhancement of Component Connectors:**

Feedback indicates that the current HPP component connectors are difficult to dismantle and not cataloged. Investing in the redesign and enhancement of these connectors could increase the recycling rate and enhance user engagement through innovative design, providing consumers with new sustainability experiences.

Conclusion

In summary, HPP events, as ephemeral retail structures, serve as effective business tools that align with current market demands and offer substantial profitability opportunities for brands. However, their brief operational lifespan, focused thematic executions, and transient venue setups contribute to significant material waste and environmental impact. Through comprehensive field research, brand consultations, and rigorous analysis of environmental data concerning Brand D's HPP events, it becomes evident that these events exert a markedly higher environmental footprint compared to conventional permanent buildings. Specifically, the daily carbon emissions of different HPP options were found to range from 162 to 1308 times that of a conventional massive building.

Furthermore, our investigation reveals that varying material choices can potentially reduce HPPs' daily carbon emissions by approximately 73%. This underscores the critical role of material selection in mitigating environmental impact within the context of pop-up retail. Notably, furniture components, particularly cabinets, emerge as pivotal areas where carbon footprint reduction efforts can be most effectively concentrated.

To address these environmental challenges, our study proposes strategies such as internal and external component reuse to extend material lifecycles. Additionally, implementing advanced warehouse management systems, modular construction techniques, and incorporating easily reconfigurable furniture and wall coverings could offer viable solutions. However, obstacles remain, including safeguarding intellectual property rights, incentivizing the use of recycled materials, and reconciling premium brand positioning with sustainable material choices.

In conclusion, this research provides valuable insights and practical guidance for environmentally conscious brands navigating the design and implementation of pop-up retail strategies. By adopting these findings, brands can align their operations with principles of sustainability and social responsibility, fostering a more balanced and sustainable societal impact.

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References

1. Yoder, C. R., Viswanathan, K. & Moore, W. L. Navigating the risks of rework in large development programs: A complex adaptive systems perspective. *Calif. Manag. Rev.* **63**, 113–140. <https://doi.org/10.1016/j.cmr.2020.07.009> (2021).
2. Huajing Industrial Research Institute. Chinese pop-up store industry market panoramic assessment and development strategy planning report, 2022–2027 (2023). (In Chinese).
3. RET. *The Power of Immobility, A Study of China's Pop-up Stores* (2016) (In Chinese). <https://www.ret.cn/in-sight/376.html>.
4. Cushman & Wakefield. *The Popularity of Pop-Up Shops* (2015).
5. Hu, F. & Zhong, H. Environmental design methods and their multidimensional analysis. *Packag. Eng.* **41**, 20–33 (2020).
6. Rebitzer, G. et al. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environ. Int.* **30**, 701–720. <https://doi.org/10.1016/j.envint.2004.06.012> (2004).
7. Eco-indicator 99. (2014). <https://pre-sustainability.com/articles/eco-indicator-99-manuals/>.
8. Goedkoop, M., & Spriensma, R. *The Eco-Indicator 99: A damage oriented method for life cycle impact assessment—Methodology report*. Pré Consultants B.V., Amersfoort, The Netherlands (2001).
9. International Energy Agency. *Europe Emissions* (2021). <https://www.iea.org/regions/europe/emissions>.

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Author contributions

D.W. and S.Z. initiated and coordinated this collaborative research project. D.W. designed the research roadmap, methodologies, analytical approaches, and was responsible for the manuscript writing. Z.R. and H.L. conducted the field research and data collection. Z.R. performed data calculations, graphical analysis, and assisted with the manuscript writing.

Declarations

Competing interests

The corresponding author, Duan Wu, on behalf of all authors (Zixin Ren, Haoyue Lei, and Shijian Zhao), declares that there are no competing interests regarding the publication of this paper. This statement confirms that none of the authors have any financial, personal, or professional conflicts that could have influenced the work reported in the manuscript.

Additional information

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Correspondence and requests for materials should be addressed to D.W.

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