

Article

The Conceptualisation of Inventive and Repurposable Children's Furniture

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Abstract: Every piece of furniture has a certain lifespan. Most furniture is eventually thrown away and ends up in landfill, thus polluting the environment. The idea of repurposability, where a product is used for another purpose at the end of its useful life, was developed to solve this problem. While there have been studies on the sustainability and innovative design of children's furniture, these studies have not considered factors such as inventiveness and repurposability. This study aimed to conceptualise inventive and repurposable children's furniture. Five concepts are proposed based on a synthesis of the patent literature, existing products and academic journals. These concepts are evaluated to determine which concept best meets eleven improvement requirements, which include improved aesthetics, cost, simplicity, manufacturability, functionality, comfort, ease of repurposing, durability, safety, sustainability and inventiveness. The result is that the invention can be used as a crib, highchair, bed safety rail, chair, pull-up bar, walker and toilet attachment. The concept is also inventive because (1) it has a large number of unique combinations of repurposable functions; (2) it has a unique shape and design that facilitate the repurposing process from one function to another; (3) it has a simple design so that users can transform the functions with ease. While retaining the added value of many repurposed functions, the extended life of this invention reduces consumer spending and saves space. This concept reduces waste and the consumption of natural resources. Further studies are needed to ensure that the concept meets all technical requirements and specifications for children's furniture, including usability and safety.



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1. Introduction

Furniture is essential in every household and is needed for a variety of activities, such as sitting, storing, eating, working and resting. As with furniture for adults, a great deal of research has been focused on the design of children's furniture. This includes a flexible design that focuses on the reliability of the materials, the robustness of the structures, functionality, innovation of the furniture, safety requirements and the requirements related to the eco-friendliness of the materials used. More fixed types of furniture with different performances have been produced, in addition to new products with multifunctional designs.

In the wood industry, various developments have been initiated to streamline sustainable processes in order to make the best use of the waste generated to create additional by-products that ultimately add value to the overall production process [1]. For instance, there have been researchers who have successfully converted green coconut waste into

coconut fibre-based particleboard that can be used for indoor furniture [2], researchers who concluded that particleboard made from agricultural biomass and recycled wood waste can ensure sustainable development [3], and researchers who assessed the suitability of agricultural lignocellulosic biomass in the form of vine pruning waste for particleboard production [4]. Other studies include research on the use of various bio-based, formaldehyde-free wood adhesives for the bonding of eco-friendly wood panels [5–7].

Reducing raw material consumption, simplifying furniture design, re-evaluating cutting techniques, reusing and recycling residual materials and extending the life of furniture are only a few approaches to sustainable furniture development [8]. Nevertheless, large amounts of waste are generated by the unbalanced use of natural resources caused by the mass production and consumption of industrial goods, with the wood industry being one of the greatest users of these resources [1].

As with any other product, every piece of furniture has a certain lifespan. As soon as it is no longer needed or its aesthetics are no longer appealing, the piece of furniture is disposed of. Such pieces of furniture often end up as waste and are eventually disposed of in landfills. Landfills have a negative impact on the environment. In 2017, approximately 80% of the 12.2 million tonnes of furniture thrown away by people in the US ended up in landfills, with only 0.3% of the waste being recyclable [9]. Similarly, Malaysians generate 38,699 tonnes of solid waste every day, and, although furniture waste statistics are unclear, old furniture is a common sight in landfills and dumps across the country [10,11].

One of the ways to address the problem of increasing waste is to develop repurposable products. Using the concept of repurposability in product design can extend the life of a product and reduce waste by transforming or repurposing the product for another function after its effective life has expired. Combining and repurposing product functions not only extends the life of the product, but also saves costs and materials.

Children's furniture is more likely to be thrown away because children grow rapidly and outgrow their furniture quickly. An effective piece of children's furniture is one that meets all the developmental needs of children without losing its functionality as children grow [12]. Under these circumstances, it would be necessary to introduce repurposability to children's furniture as this furniture has fewer years of use for its intended original use within a family. Additionally, as there are few products on the market designed for repurposability to extend their life cycle, further research on repurposable furniture, especially children's furniture, would be beneficial to society, both environmentally and financially.

1.1. Problem Statement and General Aim of Study

There are only a few studies that investigate the sustainability and innovativeness of children's furniture [13–15]. Additionally, these studies rarely consider aspects such as inventiveness and repurposability, which would extend the life cycle of used furniture. There is also a lack of published studies that address the conceptual development of inventive and repurposable children's furniture for improved functionality and life cycle extension. Therefore, this study aims to conceptualise inventive and repurposable children's furniture for improved functionality and extended use.

1.2. Strengths and Limitations in Key Findings from Past Studies

Kasai [16] designed a crib in which parent and child could sleep side by side. However, it required design considerations for the side doors and many other mechanisms. In addition, Hollis [17] designed a simple crib that could be adjusted and locked at the desired height to suit a child's needs. Unfortunately, its simple design from 1904 may not be suitable for today's consumer. Büyükpamukçu [18] investigated design considerations for children's bedroom furniture and determined the most appropriate furniture dimensions for a child. The designs included various safety features that support the well-being of a developing child. However, the study was conducted for the Turkish furniture market and may not be an accurate representation for the ASEAN market. In 2019, a crib was designed by Velkova et al. [19] to be converted into a bench and desk. While the modular

elements of this crib design are inventive, the ease of conversion between functions may not be very practical.

Sexton et al. [20] created a chest that serves as a cooler. It includes a top aperture that makes it possible to store numerous items, including food. However, for the cooler to function well, the design needs suitable insulation and materials.

A baby seat design with two complementary components that can be used individually was suggested by Hollett and Hollett [21]. Its major function is to effectively seat infants or toddlers during mealtimes or other sitting-required activities. However, the locking feature might not be sufficient to guarantee the child's safety.

Trout [22] created a walker with motion sensor systems in place. However, the motion sensing technology is expensive and challenging to use. In addition, Johnson et al. [23] created a straightforward wheeled walker for gait training. However, potential wheel slippages could endanger the stability of other repurposed operations, necessitating the adoption of locking and braking mechanisms for additional safety.

Kelleher [24] designed a toilet attachment with two rigid handholds placed on either side of the toilet bowl. The rigid handpieces can be grasped by a person to either lower themselves onto or raise themselves from the toilet seat. However, the design is mounted on the toilet, which may be unhygienic and require frequent cleaning. These tasks could be difficult for elderly people or caregivers. On the other hand, Cain and Medlock [25] have developed an attachment for a standing toilet that is not in contact with the toilet. It has a step that enables elderly people and young children to independently use a regular toilet. However, the step could also be an obstacle for adults.

A pull-up bar was created by Balentine [26] to enable efficient workouts. However, the pull-up bar's portability was limited because it had to be mounted on wall studs. Kehoe [27] created a straightforward door-mounted pull-up bar in contrast. This pull-up bar design may be connected to most standard door frames, without the need for additional locking devices. Unfortunately, this design makes it difficult to enter through the entryway because it blocks half of it.

Sundberg et al. [28] have patented a design for a foldable safety rail. It is useful for a child moving from a crib to a bed. In addition, older people can benefit from it by using it as a support to prevent them from falling out of bed. Due to its design, there is a slight bump on the bed, which can be slightly uncomfortable for some users.

Li et al. [29] designed foldable furniture with mechanisms to facilitate switching from one function to another. Steffen and Gros [30] investigated an original modular furniture design with integrated CNC milling. However, CNC milling may not be readily accessible or common in furniture manufacturing. In terms of space saving, Safa [31] designed multifunctional storage systems, while Ertaş and Şatır [32] designed a bed that can be transformed into a worktable and a rest area. Although the designs are multifunctional and inventive, the numerous mechanisms could be challenging to assemble.

To determine the best sizes for dressers, beds and desks, Rim et al. [33] conducted an analysis of children's furniture. For the ASEAN population, the dimensions might need to be re-evaluated. Furniture with many uses has also been created by Rajan et al. [34]; Dovramadjiev et al. [35]; and Domljan and Vlaović [36]. In conclusion, while multifunctionality is a beneficial aspect of this project, it is indeed crucial to remember that the project's main focus is on repurposability. Therefore, this project may adopt multifunctionality-related features as long as those features also serve the idea of repurposability.

The merits and limitations of each patent, thesis, journal article and conference paper are listed in Table 1, which provides a synthesis of the major findings from prior investigations.

Table 1. Synthesis of key findings from past studies (strengths and limitations).

Content	Author	Source	Strengths	Limitations
Crib design	Kasai [16]	Patent	<ul style="list-style-type: none"> Enables parents and children to share a bed Offers a child a more secure sleeping environment 	<ul style="list-style-type: none"> Requires design considerations for the side door Requires additional mechanisms
	Hollis [17]	Patent	<ul style="list-style-type: none"> Features parts that are simple to disassemble Can be raised to the necessary height Can be locked in various positions Gives children a safer place to rest 	<ul style="list-style-type: none"> The mechanism for height adjustment requires different dimensions of the beams, which can be difficult to manufacture The material used (wood) may not be suitable for the project at hand Outdated design from the 1900s
	Büyükpamukçu [18]	Master's thesis	<ul style="list-style-type: none"> Accurate crib dimensions for a child Crib safety design features Can be converted into a bed Multifunctional 	<ul style="list-style-type: none"> Wood-based design Survey only within the Turkish market
Chest design	Sexton, Simoni and Brown [20]	Patent	<ul style="list-style-type: none"> Opening at the top for access to the inside of the chest Allows the storage of various items 	<ul style="list-style-type: none"> Includes a cooling system that requires many materials and insulation components to function
Baby seat design	Hollett and Hollett [21]	Patent	<ul style="list-style-type: none"> Two complementary parts that can be used separately Makes it easier for babies and toddlers to sit down during mealtimes or other sitting activities 	<ul style="list-style-type: none"> The mechanisms of the locking component may not be stable enough to ensure the child's safety
Walker	Trout [22]	Patent	<ul style="list-style-type: none"> Includes a motion sensor to detect users' movements Reliable aluminium material 	<ul style="list-style-type: none"> Difficult to integrate the motion sensor into the assembly Costly to manufacture Requires additional components Motion detection is not considered within the topic of the present project
	Johnson, Hauck, Osland, Johnson and Bobgan [23]	Patent	<ul style="list-style-type: none"> Walking aid with wheels Device for gait training Device for rehabilitation of people with an injury, stroke or neurological disorder or for use by elderly or disabled people Reliable aluminium material 	<ul style="list-style-type: none"> Wheels could affect the overall stability of other converted functions Requires the implementation of locking and braking mechanisms for the wheels
Toilet attachment	Kelleher [24]	Patent	<ul style="list-style-type: none"> Two handholds placed on either side of the toilet bowl Rigid handpieces that can be grasped by users to sit on or stand up from the toilet seat 	<ul style="list-style-type: none"> The design is mounted on the toilet bowl Unhygienic and may need frequent cleaning The design is difficult to integrate and has unique dimensions compared to other products
	Cain and Medlock [25]	Patent	<ul style="list-style-type: none"> With vertically adjustable legs on both sides of the toilet bowl Includes a U-shaped element with a strong rubbing surface for better grip Helps children and older people to use a conventional toilet Provides steps for children to easily reach the toilet 	<ul style="list-style-type: none"> The steps could be an obstacle for adult users
Pull-up bar	Balentine [26]	Patent	<ul style="list-style-type: none"> A design that enables effective training Reliable combination of materials used (aluminium and steel) 	<ul style="list-style-type: none"> Wall studs or ceiling connections are required for mounting, which require power tools The unit is tied to a specific position and is not portable
	Kehoe [27]	Patent	<ul style="list-style-type: none"> A simple and effective design No security mechanisms are required It can be attached directly to most doors It allows various other exercises in addition to pull-ups 	<ul style="list-style-type: none"> It can block the door It must be attached and removed frequently so as not to block the doorway

Table 1. *Cont.*

Content	Author	Source	Strengths	Limitations
Safety rail	Sundberg, Ordung and Bernstein [28]	Patent	<ul style="list-style-type: none"> Collapsible design for convenient storage Easy to dismantle with removable parts Vertical extension that fits under the bed Used for the transition from crib to bed Prevents the user from falling out of bed 	<ul style="list-style-type: none"> May cause a slight bump in the bed, which may be uncomfortable for the user
Furniture design	Li, Hu, Alhashim and Zhang [29]	Journal	<ul style="list-style-type: none"> Creative furniture design Folding mechanisms included 	<ul style="list-style-type: none"> Places more value on multifunctionality than on repurposability
	Steffen and Gros [30]	Conference paper	<ul style="list-style-type: none"> Modular furniture design Collapsible chair and table Integration of CNC milling 	<ul style="list-style-type: none"> The integration of CNC milling can be costly
	Safa [31]	Master's thesis	<ul style="list-style-type: none"> Multifunctional storage system Inventive design 	<ul style="list-style-type: none"> Contains numerous mechanisms that are difficult to integrate into the assembly
	Ertaş and Şatır [32]	Journal	<ul style="list-style-type: none"> Several transformations Convertible into a bed, a worktable and a reclining surface 	<ul style="list-style-type: none"> The functions are quite common The transformation of large furniture may not be user-friendly
Furniture design	Rim, Kang and Cho [33]	Journal	<ul style="list-style-type: none"> Detailed analysis of different children's furniture Provides features and benefits of different children's beds Exact measurements for a chest of drawers, a bed and a desk 	<ul style="list-style-type: none"> The functions are rather ordinary The aspect of repurposability is missing
	Rajan, Elavarasan, Balaji, Dinesh and Gowtham [34]	Journal	<ul style="list-style-type: none"> Space-saving furniture design Modular and flexible furniture design Analysis and simulation of aluminium furniture 	<ul style="list-style-type: none"> Places more value on multifunctionality than on repurposability
	Dovramadjiev, Bratanov, Cankova and Jecheva [35]	Journal	<ul style="list-style-type: none"> Modular and multifunctional furniture Furniture can be reassembled for different functions Compact CAD-designed furniture 	<ul style="list-style-type: none"> The conceptual designs can be a challenge to produce
	Domljan and Vlaović [36]	Conference proceeding paper	<ul style="list-style-type: none"> Conceptual design of a piece of furniture with partial functions for sitting and lying down The partial functions and the overall function can be changed by altering the materials and the form 	<ul style="list-style-type: none"> Only for activities involving sitting and lying down

1.3. Literature Synthesis and Research Gaps from Recent Study Findings

Salvador [15] conducted research on how ergonomics can affect furniture for children in a sustainable way. However, apart from high chairs, there were no other furniture designs that focused on repurposability. Han, Li, Jiang and Wang [14] conducted studies on the application of innovative technologies in the design of children's furniture. One of the limitations was the limited number of repurposable transformations among the inventions. The inventions could only be repurposed once. With a larger number of repurposable transformations, the overall lifespan and functionality of the inventions could be improved. In addition, the repurposable transformations contained ordinary functions and were not particularly inventive.

Aguirre [13] conducted a study on design for repurposing, which also concluded that there are only a limited number of repurposable transformations for the inventions discussed in the study. This limitation may affect the potential of the invention to improve its life cycle. Table 2 summarises the literature synthesis and research gaps of the recent study results, outlining the main limitations of each journal and dissertation.

Table 2. Summary of the literature synthesis and research gaps for more recent studies.

Content	Author	Source	Content	Key Limitations	Research Gaps
Contributions of Ergonomics to Effective Sustainability in Children’s Furniture	Salvador [15]	Journal	<ul style="list-style-type: none"> Identify problems that hinder sustainability, leading to waste reduction and product optimisation. Research into product design to find solutions that enable the extension of the product life cycle and contribute to sustainable development. 	<ul style="list-style-type: none"> Apart from the highchair, there were no other furniture designs that focused on repurposability. 	<ul style="list-style-type: none"> Lack of repurposability.
Application of Innovative Technology in Children’s Furniture Design	Han, Li, Jiang and Wang [14]	Journal	<ul style="list-style-type: none"> Design of multipurpose furniture. Innovative furniture for the benefit of the market and the user. 	<ul style="list-style-type: none"> Limited number of transformations for repurposability. Limited lifespan of children’s furniture. Common transformations. 	<ul style="list-style-type: none"> Limited number of transformations. Lack of inventive transformations.
Design for Repurposing	Aguirre [13]	Thesis	<ul style="list-style-type: none"> Aims to extend the longevity of products by intentionally designing features or details that facilitate repurposing. Designing objects with a second life in mind. Repurposing to transform products or their components for a second purpose after their first purpose has expired. Reducing the amount of waste in landfills and saving energy, money and the environment. Valuable materials and energy are saved. It preserves natural resources for future generations. 	<ul style="list-style-type: none"> Limited number of transformations for repurposability. Short life cycle for each product due to limited number of transformations. 	<ul style="list-style-type: none"> Limited number of transformations.

1.4. Research Gaps, Problem Statement and Aim of Study

According to the previous literature synthesis, most repurposed furniture designs use ordinary and common functions between transformations. Some of these transformations can be seen in the modern furniture market. A common example is a bed that is transformed into a chair. Thus, there is a lack of inventiveness in transforming furniture that can be repurposed. This problem could be due to the fact that repurposability has not been widely researched. Furthermore, the number of transformations is low, leading to a reduction in the overall functionality of the product.

In summary, it appears that no research has been published on the conceptualisation of inventive and repurposable children’s furniture for better functionality that would promote extended use. To increase functionality and extended use, this study aims to conceptualise inventive and repurposable children’s furniture.

2. Methodology

The conceptualisation technique used in this study is illustrated in Figure 1. The technique includes functional extraction, concept drawing, concept screening and final concept selection. Functional screening identifies relevant innovations and concepts in a variety of sources, including existing products, patents and journal articles.

A total of five concepts are created by combining the features, functions and ideas from functional extraction. Autodesk Inventor Professional (version 2019) is used to sketch the ideas. For each concept, there are detailed explanations of how it works.

Based on a set of criteria that are used to assess the concepts, concept screening aids in the identification of relevant concepts. Aesthetics, cost, simplicity, manufacturability, functionality, comfort, ease of repurposing, durability, safety, sustainability and inventiveness are among the criteria used for screening, evaluating and selecting concepts.

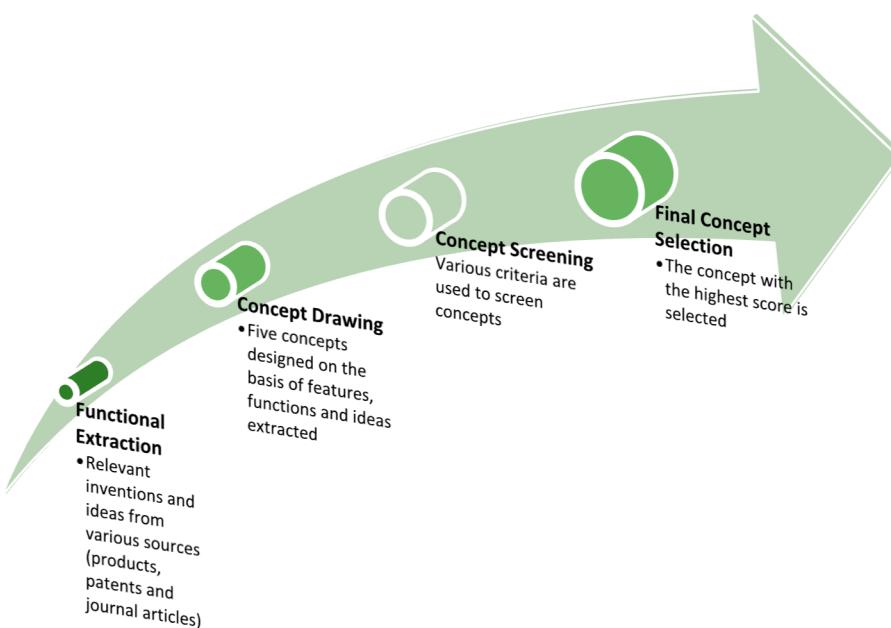


Figure 1. Conceptualisation technique.

Aesthetics, functionality and safety were chosen as selection criteria because they play an important role in furniture quality and preference, especially in terms of furnishing style [37–39]. Durability and manufacturability are also important selection criteria, as these factors are preferred by furniture manufacturers, especially those producing environmentally friendly furniture from lightweight wood-based panels [40]. In relation to the criteria of functionality and manufacturability, Poole [41] suggested that the functional requirements of items and the limitations of manufacturing methods and processes are important factors to consider for furnishing. Cost is also a selection criterion, as it is one of the most important factors influencing Malaysian furniture manufacturers' decisions to produce value-added wood products [42]. In addition, simplicity is also an important criterion for achieving iconic quality in furniture designs [43].

Another important criterion is the ease of repurposing as it involves recreating a waste item for another functional purpose [44], which makes the design environmentally sustainable [45]. Sustainability is also important in product development to protect the environment throughout the life cycle of the product, from the raw material phase to final disposal. Comfort is an important criterion to consider in furniture design because it is focused on the user's need for a better fit [46]. Finally, the criterion of inventiveness is important because the product should be original and easily distinguishable from existing products on the market [47].

One of the concepts is chosen as a reference during the concept screening stage. If the other concepts outperform the reference in terms of the criteria, the symbol “+” is applied to them. The other concepts are given the symbol “-” if their performance falls short of the reference's performance based on the criteria, and the other concepts are given the symbol “0” if their performance is on par with the reference's performance based on the criteria. The three concepts with the highest net scores are selected for further analysis. The net score is determined on the basis of the positive and negative values.

Similar criteria (aesthetics, cost, simplicity, manufacturability, functionality, ease of repurposing, durability, safety, sustainability and inventiveness) were used to evaluate the other concepts, as they are crucial to the production of the invention proposed in this study.

The weighted score that a given concept receives for each criterion is calculated by multiplying the rated score by the criteria weight, in which summing the products gives the total weighted score:

$$WS_j = \sum_{i=1}^n R_{ij}W_i \quad (1)$$

where

R_{ij} = rating of concept j for i^{th} criterion;

W_i = weight for i^{th} criterion;

n = number of criteria;

WS_j = total weighted score for concept j .

Each concept receives a rating on a five-point scale according to the criteria. Given below are the definitions of the ratings:

1. poor fulfilment of the criterion;
2. unsatisfactory fulfilment of the criterion;
3. satisfactory fulfilment of the criterion;
4. good fulfilment of the criterion;
5. excellent fulfilment of the criterion.

The ranking of each concept is reflected in its total weighted score. The concept with the highest score will be selected as the final design that addresses the issues in this study.

3. Results and Discussion

3.1. Functional Extraction

Table 3 shows the functions of furniture and products that can be considered in the conceptual phase. It is important to note that the conceptualisation process began with reference to different types of furniture in addition to children's furniture. However, in the end, the baby crib was chosen as an existing product to be observed. Apart from its frequent use, it was found that this piece of children's furniture often has defects that can lead to injuries and death in the children who use it [48,49]. To avoid this critical risk at the design stage, the authors decided to consider the design of the baby crib for this study.

Table 3. Repurposable functions of products and furniture.

Category	Products/Furniture	Repurposing Functions	Sources
Existing product (based on own observations)	Crib Door	<ul style="list-style-type: none"> • Safety door • Pull-up bar • Drying rack 	[50–52]
	Bed Frame	<ul style="list-style-type: none"> • Foldable ladder • Outdoor bath • Bed safety rail 	[53–56]
	Chair	<ul style="list-style-type: none"> • Walker • Elderly/child toilet attachment • Trolley 	[57–59]
	Stepladder	<ul style="list-style-type: none"> • Stepladder • Children's table 	[60]
	Transforming Modular Furniture	<ul style="list-style-type: none"> • Table • Chair • Cupboard 	[61]
	Multifunctional Crib	<ul style="list-style-type: none"> • Table • Chairs 	[62]
Patents	Crib Design	<ul style="list-style-type: none"> • Adult bed • Table • Chairs 	[63]
	Crib Patent	Crib design	[64]

Table 3. Cont.

Category	Products/Furniture	Repurposing Functions	Sources
Journals	Crib	<ul style="list-style-type: none"> • Crib design • Convertible furniture 	[18,65]
	Foldable Bed	<ul style="list-style-type: none"> • Foldable bed • Table 	[32,66,67]
	Children's Furniture	Children's furniture design	[33,68]
	Chair	Foldable chair	[29,69]
	Disinfection Booth	Reduce transmission of COVID-19	[70,71]

3.2. Concept Drawing

Autodesk Inventor 2019 is used to design five concepts that contain the previously extracted repurposing functions.

Concept 1: The main function of this concept includes a baby's crib, as shown in Figure 2a. The crib is a safe and comfortable place for the baby to rest and sleep. When the baby has outgrown the crib, the frame of the crib can be removed and converted into a padded seat, as shown in Figure 2b. When the storage box is removed, two converted chairs are revealed, as shown in Figure 2c. The chairs provide a comfortable place to sit and rest in general. Each of these chairs can be converted into a highchair, as shown in Figure 2d. The highchair is suitable for a small child. It provides a safe place for the child to sit during mealtimes. When the highchair has outlived its useful life, it can be converted into a walker, as shown in Figure 2e, by removing the wooden panels. The walker is suitable for elderly or disabled people, as it provides extra support when walking. The walker can be converted into a toilet attachment, as shown in Figure 2f. The toilet attachment is mounted around the toilet bowl. It has handlebars that make it easier to sit on and stand up from the toilet. Users can also use it to lift themselves up after a slip, as there are handlebars on the side of the toilet attachment. When the toilet seat has reached the end of its life cycle, it can be taken apart and assembled into a pull-up bar, as shown in Figure 2g. The pull-up bar allows the user or even a growing child to exercise and lead an active and healthy lifestyle. Finally, the toilet attachment can also be converted into a safety rail, as shown in Figure 2h. The safety rail is attached to the side of a bed and prevents a child or elderly person from falling out of bed and becoming seriously injured.

Concept 2: The main function of this concept includes a crib, as shown in Figure 3a. The crib provides a safe place for the child to rest and sleep. Once the child has outgrown the crib, the padding can be removed to provide access to a barbecue grill, as shown in Figure 3b. The barbecue grill can be used to prepare simple meals. In addition, the metal door of the crib can be converted into a safety door, as shown in Figure 3c. The safety door can be placed in walkways or stairways to protect the child from unforeseen accidents, such as falling down the stairs or slipping off the walkway. The safety door can then be converted into a drying rack, as shown in Figure 3d. The drying rack provides space to hang and dry clothes indoors on a rainy day. Finally, the drying rack can be taken apart and used as a pull-up bar for exercise purposes, as shown in Figure 3e. The pull-up bar can be attached to a doorway and provides a growing child with much-needed exercise for a healthy lifestyle.

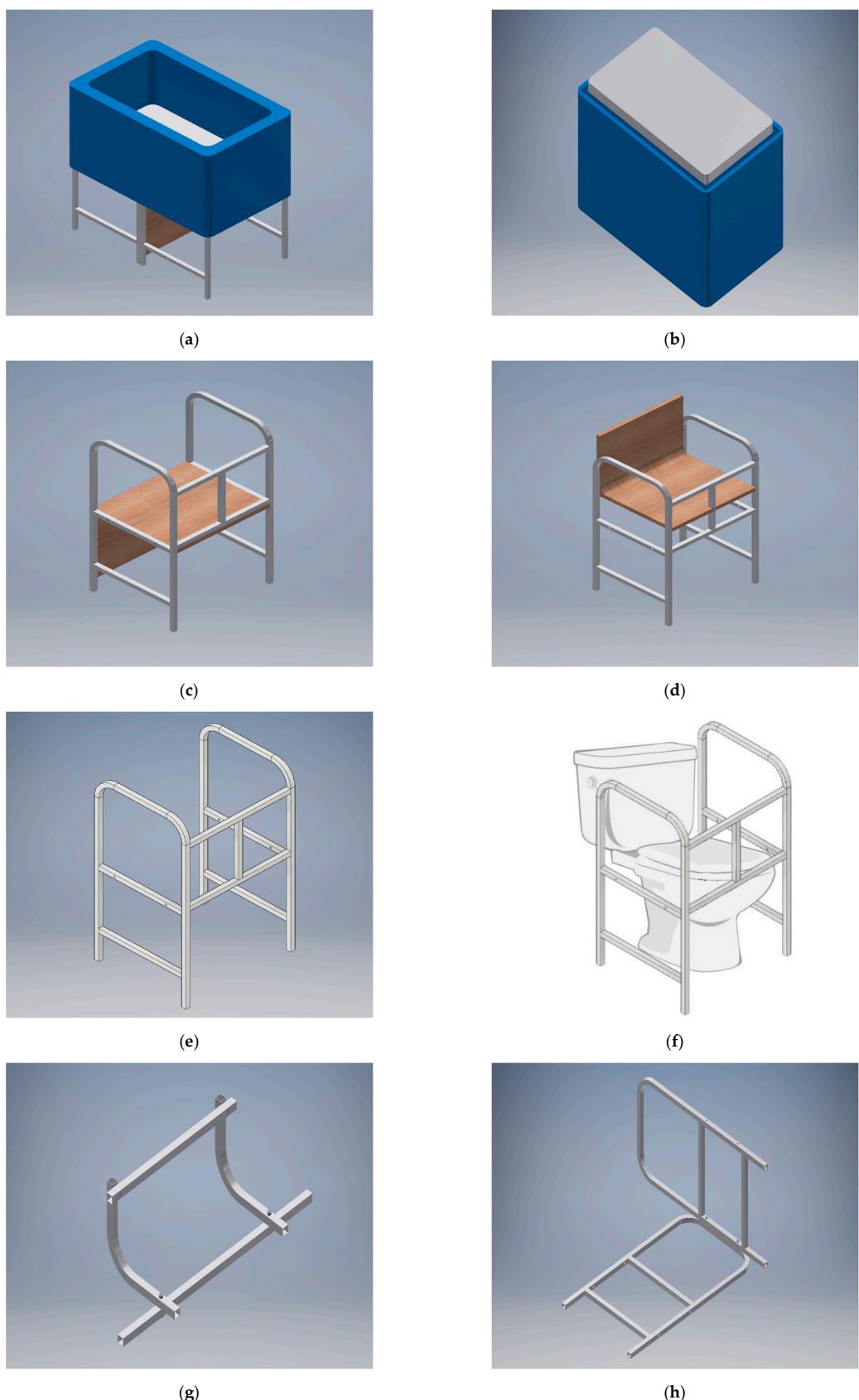


Figure 2. Designs for repurposed parts of concept 1. (a) Crib design. (b) Cushioned seat design. (c) Chair design. (d) Highchair design. (e) Walker design. (f) Toilet attachment design. (g) Pull-up bar design. (h) Safety rail design.

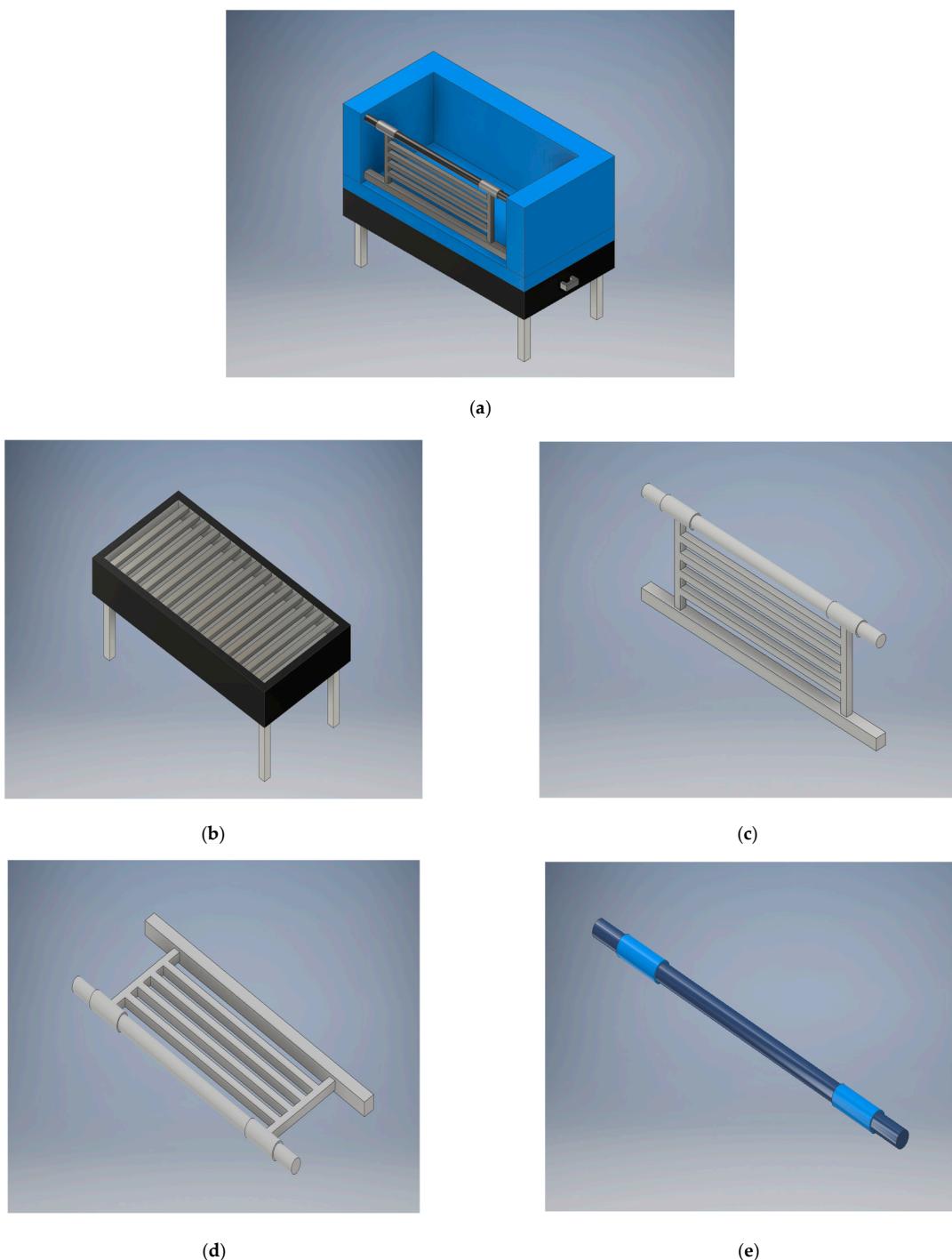


Figure 3. Repurposed parts of concept 2. (a) Crib design. (b) Grill design. (c) Safety door design. (d) Drying rack design. (e) Pull-up bar design.

Concept 3: This concept includes ideas from concepts 1 and 2. It also includes a crib, as shown in Figure 4a. Once the child has outgrown the crib, the sides of the crib can be removed and used as chairs (see Figure 4b) for domestic purposes. The cushions in the centre of the crib can be removed to give access to a barbecue grill for light cooking activities, as shown in Figure 4c. The metal door of the crib can be converted into a safety door, as shown in Figure 4d. The safety door can be placed in walkways or stairways to prevent unforeseen accidents involving young children, such as falling down the stairs or falling off the walkway. The safety door can then be converted into a drying rack for hanging and drying clothes indoors, as shown in Figure 4e. Finally, the drying rack can be

taken apart and used as a pull-up bar for exercise purposes, as shown in Figure 4f. The pull-up bar can be attached to a doorway.

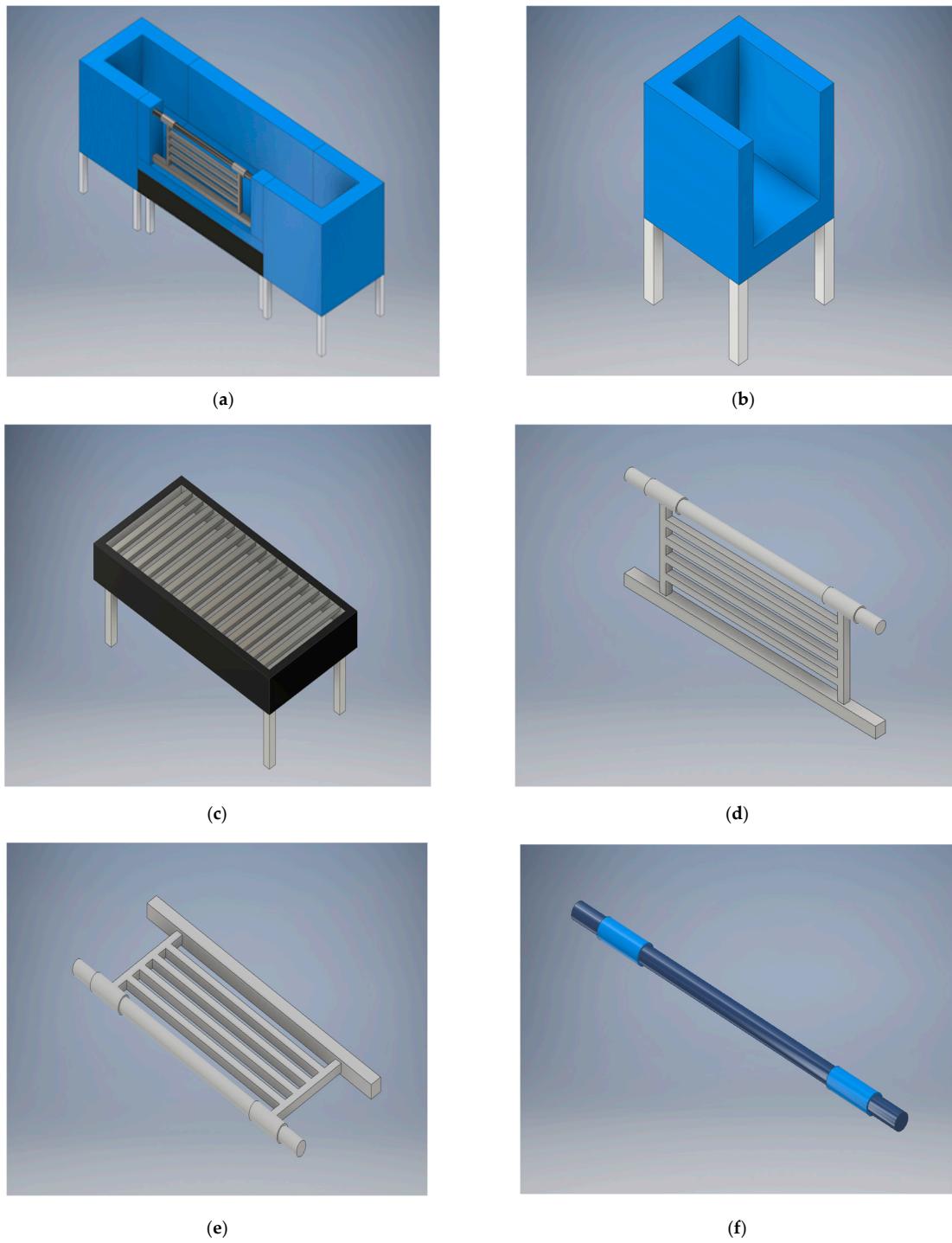


Figure 4. Repurposed parts of concept 3. (a) Crib design. (b) Chair design. (c) Grill design. (d) Safety door design. (e) Drying rack design. (f) Pull-up bar design.

Concept 4: The main function of this concept also includes a crib, as shown in Figure 5a. When the child has outgrown the crib, the padding can be removed to provide an access ramp, as shown in Figure 5b. The ramp is useful as a storage space for households with wheeled devices, such as prams or wheelchairs. The wheels of the wheeled devices may be inserted into the openings in the ramp to keep the devices stationary. In addition, the

crib can be converted into a bicycle stand, as shown in Figure 5c, where the wheels can be placed in the openings of the stand to ensure that the bicycle remains stationary. The bicycle stand is a useful bicycle storage facility for families who maintain a healthy cycling lifestyle. If the bicycle stand is repositioned, it can be converted into an outdoor shower structure, as shown in Figure 5d. This structure can possibly be integrated into a shower so that people can clean themselves comfortably and hygienically before entering their house. Such an idea can be useful to improve hygiene, especially during a pandemic caused by viruses spread by droplet transmission and close contact, such as COVID-19. Finally, the outdoor shower structure can also be converted into a physical training device. The equipment in Figure 5e can be used as an outdoor pull-up bar or an exercise bench, offering users the opportunity to maintain a healthier lifestyle.

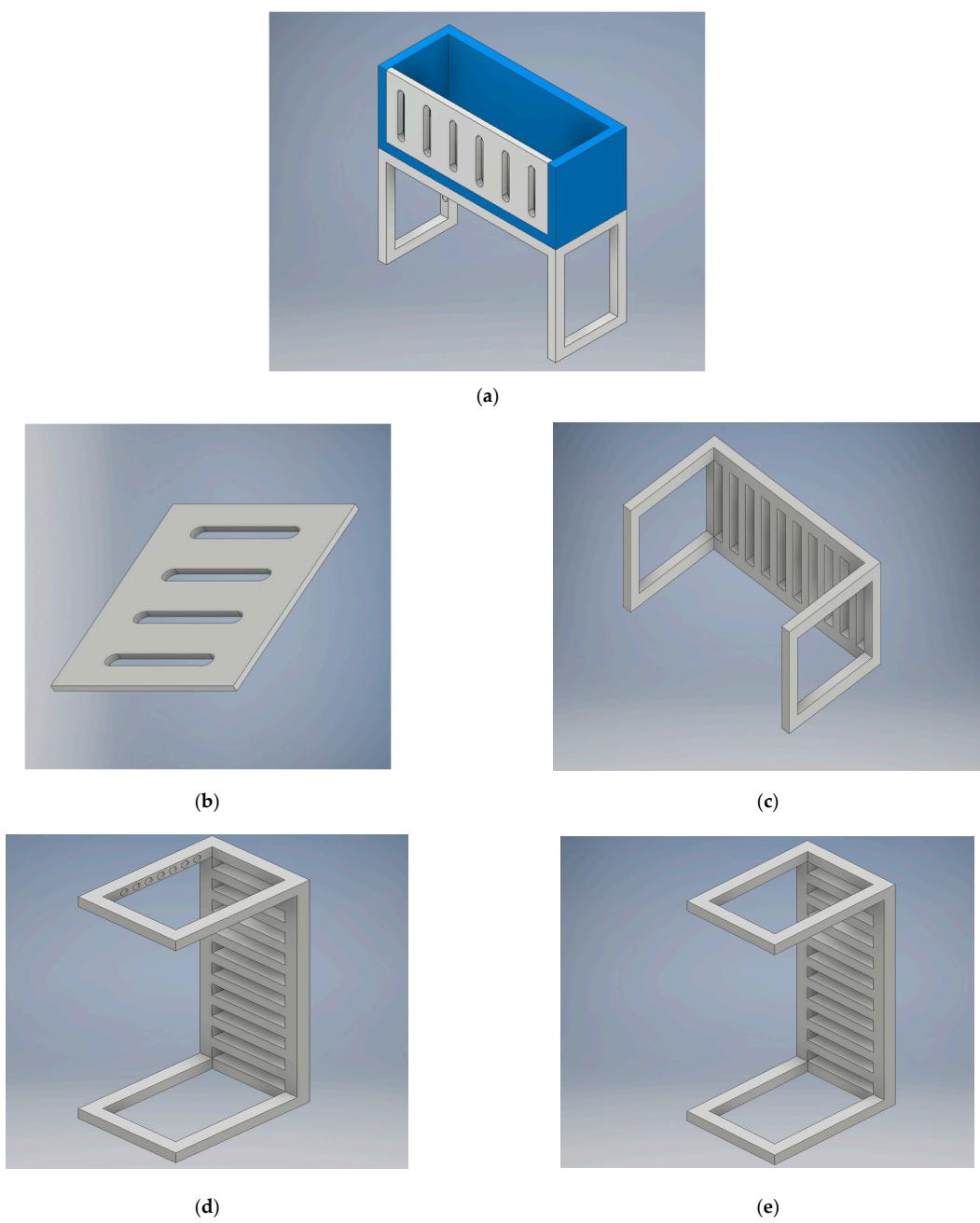


Figure 5. Repurposed parts of concept 4. (a) Crib design. (b) Ramp design. (c) Bicycle stand design. (d) Outdoor shower structure. (e) Exercise equipment structure.

Concept 5: The main function of this concept also includes a crib, as shown in Figure 6a. Once the child has outgrown the crib, the padding can be removed to give access to conveyor belt wheels, as shown in Figure 6b, which can be used as a conveyor belt system to load heavy items into the car boot. The conveyor belt can be converted into an outdoor treadmill for exercise, as shown in Figure 6c. Users can walk on the wheels of the treadmill, which were originally used as conveyor belt wheels for transporting objects. Once the treadmill is no longer needed, it can be converted into a pushcart, as shown in Figure 6d. The pushcart wheels were originally the treadmill wheels of the previous design. With the pushcart, the user can easily transport heavy objects. Finally, the frame of the crib can be converted into a bicycle stand, as shown in Figure 6e. The bicycle stand is provided with slots in which the bicycle tyres can be placed and secured.

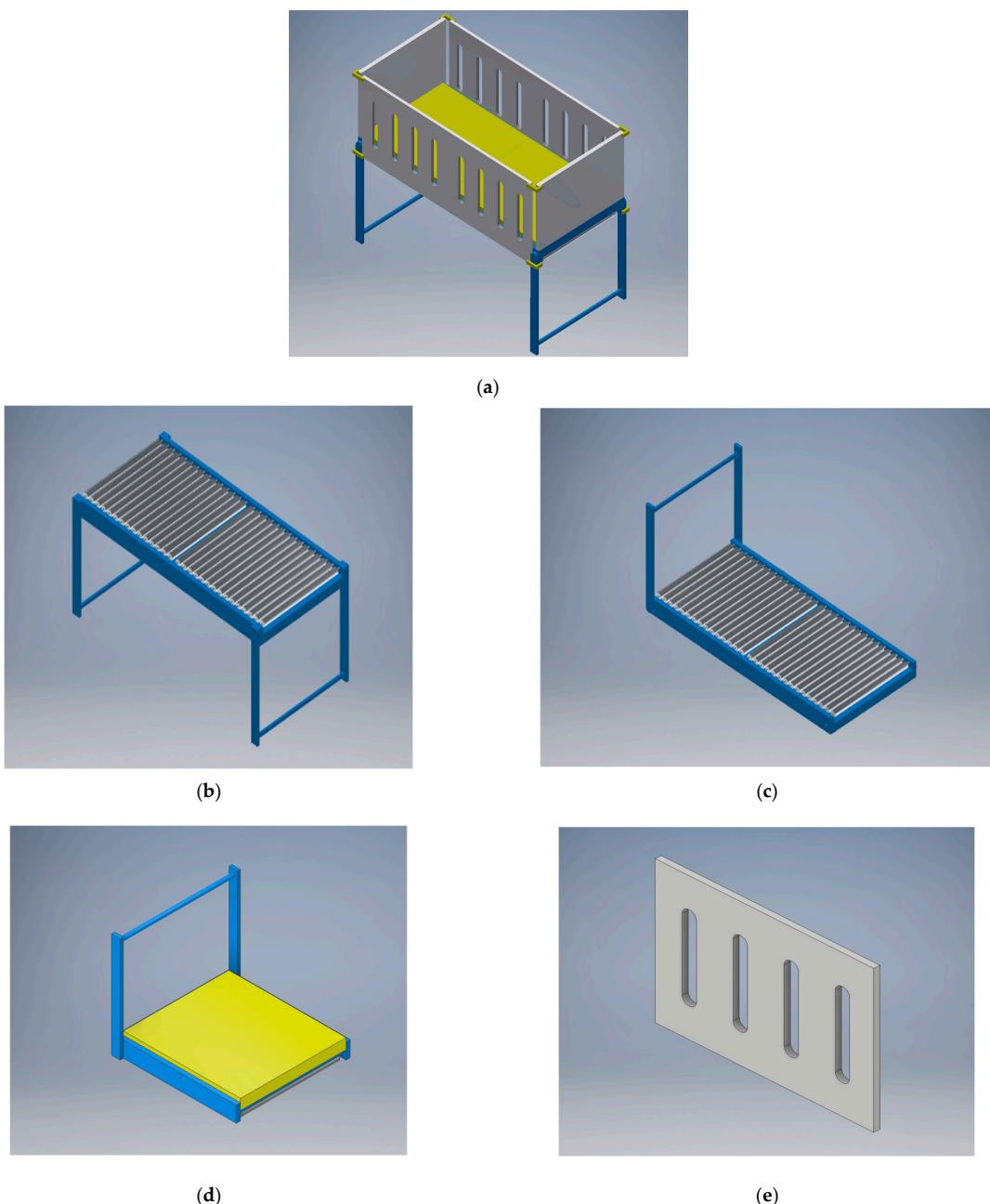


Figure 6. Repurposed parts of concept 5. (a) Crib design. (b) Conveyer belt design. (c) Treadmill design. (d) Pushcart design. (e) Bicycle stand design.

3.3. Concept Screening

The concept designs are screened based on eleven criteria. These criteria include aesthetics, cost, simplicity, manufacturability, functionality, ease of repurposing, durability, safety, sustainability and inventiveness. The concept screening results, which compare the advantages and disadvantages of each concept design, can be found in Table 4. The five concepts are evaluated against the above criteria. Concept 1 was selected as the reference concept because of its simplicity, inventiveness and manufacturability. The reference concept is compared with concepts 2 to 5. Based on the net score, the three best concepts (concepts 1, 2 and 5) were selected for further concept evaluation.

Table 4. Concept screening table.

Criteria	Concept 1 (Reference)	Concept 2	Concept 3	Concept 4	Concept 5
Aesthetics	0	0	-	-	-
Cost	0	-	-	-	-
Simplicity	0	0	-	-	-
Manufacturability	0	-	-	-	-
Functionality	0	+	+	+	+
Comfort	0	-	-	-	-
Ease of repurposing	0	+	-	-	+
Durability	0	0	+	+	+
Safety	0	-	0	-	0
Sustainability	0	+	+	+	+
Inventiveness	0	-	-	-	-
Sum '+'	0	3	4	4	4
Sum '0'	10	3	1	0	1
Sum '-'	0	4	6	7	5
Net score	0	-1	-2	-3	-1
Ranking	1	2	3	4	1
Decision	Continue	Continue	Eliminated	Eliminated	Continue

3.4. Final Concept Selection

The concept evaluation matrix used to identify the chosen concept is shown in Table 5. Depending on how important it is to the project, each criterion was assigned a certain weight. The scores for the draft ideas range from 1 to 5. The concept that was selected as the final concept is the one with the highest weighted score. Comparing concept 1 with the other concepts, concept 1 is found to be superior in the majority of the criteria. Therefore, concept 1 is selected as the final design.

The selected concept (concept 1) is an invention relating to children's furniture that can be converted into a variety of other objects to extend its useful life. Each product function for which the invention is repurposed is used until it is no longer needed (e.g., when a child has outgrown the use of a crib). The function is then converted into the following, most practical function (e.g., a highchair for an older child or a normal chair for an adult).

The invention's usefulness can be extended to up to seven functions, including a crib for young children, a highchair for older children, a bed safety rail for older children, a chair for adults or young people, a pull-up bar for adults or children, a walker for the elderly and a toilet attachment for the elderly. An increased level of multifunctionality is beneficial for multiple users as it is able to meet the needs of all types of users, especially

those who populate urban communal spaces [72,73]. The universality of this concept is an important reference for design researchers who have studied innovative furniture for the future integration of design elements and functionalities in their study [74–76].

Table 5. Concept evaluation table.

Criteria	Weighting (%)	Concept 1	%	Concept 2	%	Concept 5	%
Aesthetics	5	4	0.20	4	0.20	3	0.15
Cost	10	5	0.50	3	0.30	2	0.20
Simplicity	10	5	0.50	4	0.40	3	0.30
Manufacturability	15	4	0.60	3	0.45	2	0.30
Functionality	10	5	0.50	4	0.40	4	0.40
Comfort	5	3	0.15	4	0.20	3	0.15
Ease of repurposing	15	4	0.60	3	0.45	4	0.60
Durability	10	4	0.40	3	0.30	2	0.20
Safety	5	4	0.20	2	0.10	3	0.15
Sustainability	5	2	0.10	4	0.20	4	0.20
Inventiveness	10	4	0.4	3	0.30	3	0.30
Weighted score		4.15		3.30		2.95	
Ranking		1		2		3	
Decision		Chosen		Eliminated		Eliminated	

3.4.1. Repurposability

The primary goal of this invention is to help the main users of the household (parents, guardians and users who buy furniture for their families) to reduce the amount of furniture or tools that are thrown away by transforming only one piece of furniture for another function after it has fulfilled its intended purpose. Although people's lifestyles may be different, this concept is also useful in educating families to live a sustainable lifestyle through sustainable waste management, where the principle is not to throw away items but to repurpose and reuse them for as long as possible [77]. By reducing the number of items needed for different domestic functions, this device also aims to save money and space. Cost-efficient and space-saving furniture designs are very popular among customers as such designs improve the interior of the home [78]. Therefore, integrating the concept of repurposability into furniture is important for its future marketability.

The concept of this study for repurposed children's furniture is environmentally friendly. Since a piece of furniture has multiple functions, the energy consumption for the production of the furniture can be reduced, resulting in lower pollutant emissions and waste being released into the environment [79,80]. The release of toxic substances in the production of this reused furniture, such as polishes, wood dyes, glues, ketones, ethanol and fragrances, can also be reduced [79].

3.4.2. Inventive Features

The first inventive feature that can be protected is the unique combination of repurposable functions in the invention. Repurposable furniture is usually limited to being repurposed into other furniture. However, the proposed invention has not been limited to the furniture category. For example, the proposed invention has seven repurposable transformations that include a cushioned seat, a chair, a highchair, a walker for the elderly, a toilet attachment, a pull-up bar and a bed safety rail. The presence of multiple transformations is useful in extending the life of a product, as tools and equipment that are less useful are discarded over time, while those that are more universal and multifunctional remain in use [81]. A combination of a walker, toilet attachment, pull-up bar and bed safety

rail integrated into the design of a repurposable crib or children's furniture has never been seen before. Moreover, there has never been a repurposable invention that also has such extensive repurposable features, ranging from supporting infants to older children, teenagers, adults and the elderly. Thus, the invention is unique in the repurposable furniture category.

The second most inventive feature to consider is the unique shape and design of the invention. It is necessary to provide a furniture concept that allows for a variety of postures, to adapt to personal differences in size and shape, so each user can use the furniture according to their body measurements and postural preferences [82]. The proposed invention has been modelled so that its shape and design overlap with its other repurposable functions. For example, the chair has been designed so that the wooden seat can be easily removed to expose the frame of the elderly walker. This feature provides the user with an easy repurposing process. This design consideration was also made for the elderly walker and most of the repurposable functions of the invention. When choosing furniture, older people often focus on functionality and consider the ease and convenience of unfolding, comfortable suspension and multifunctionality of the furniture [83]. The design and concept of the unique transformation features, such as the chair into a walker, the toilet attachment, the bed safety rail and the pull-up bar, can also be protected. In addition, many parts of the invention have a unique design that can be protected, such as the padded seat. The padded seat has been designed to clip onto the metal frames of the two chairs to form the crib.

The third inventive feature that may be considered is the unique repurposing processes of the proposed invention. The repurposing processes of the invention are simple yet unique. For example, the wooden crib was designed so that the grooves perfectly enclose the two chairs. At this stage, the chairs serve as the base and legs of the crib. To repurpose the crib into chairs, the user is merely required to lift and turn the wooden crib over and place the crib cushions on the turned-over crib and the repurposing process is complete. Simplicity in design improves the demand of the furniture sold, because simple furniture designs are associated with low prices, which is a favourable aspect among many consumers [84–86]. The steps and the idea of the repurposing process can be protected. The conversion of the chair into a highchair is also unique. The seat of the chair consists of two layers of wood stacked on top of each other, with a hinge on the side. This not only gives the seat extra stability when used as an adult chair, but also allows a piece of the wood to be folded up and used as a backrest for the child's seat. This unique seat design and the repurposing process can both be protected.

4. Conclusions

The aim of this study was to conceptualise inventive and repurposable children's furniture for improved functionality and promote extended use. Enhancing repurposability and inventiveness was the overarching goal of the conceptualisation. Consequently, a repurposable crib concept with seven uses was proposed: a crib, a highchair, a bed safety rail, a chair, a pull-up bar, a walker and a toilet attachment. In terms of inventiveness, the concept is inventive because: (1) it has a large number of unique combinations of repurposable functions; (2) it has a unique shape and design that facilitate the repurposing process from one function to another; and (3) it has a simple design so that users can transform the functions with ease.

The novelty of this study is the conception of a repurposable crib with functions and customisation possibilities that do not yet exist on the market. In addition to starting a trend in the furniture market due to its good value for money, furniture manufacturers could sell the product by emphasising its sustainability and excellent functionality to attract young people and customers who share their progressive views. Given the recent growth of the market for sustainable products, this could lead to strong market potential for the product.

The furniture manufacturer may also divide the invention into several products. For example, the crib can be transformed into a chair with a padded seat, a walker with a toilet attachment and a bed safety rail. In this way, the company can sell a wider variety of

products. This study is also useful for researchers investigating the role of repurposable furniture in smart cities or smart sustainable homes that aim to save space.

In the future, it may be important to consider improving the design of the proposed invention so that it can be disassembled and reassembled into different parts. Thus, in addition to the intended transformations for which it is designed, it can be transformed into any object desired by the user according to his or her creativity—for example, a one-handed walking stick or a hooked ladder.

Further studies are needed to ensure that the idea meets all technical standards and specifications for children's furniture, including usability and safety. Experimental trials and usability tests can also be used to identify design changes or modifications. Collaboration with furniture manufacturers is possible to further develop the research and design for improved feasibility.

Limitations of Study

One of the limitations of this study was the lack of a usability feedback study among actual users before the conceptual design process took place. The researchers relied mainly on designs from patents and the scientific literature. Another limitation was the lack of use of creative ideation tools, such as design thinking, the theory of inventive problem solving (TRIZ) or lateral thinking in the conceptual design process, which could have improved or accelerated the standard conceptualisation process. Finally, the ranking of the concepts was performed by the lead author with the advice of the other co-authors, which might imply some bias. In the future, it would be preferable if more than one person were involved in the ranking process to improve the inter-rater reliability.

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