

**An Approach for Designing a More Sustainable
Toy Through Modularity and Multiple Functions**

by

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Abstract

Mass-produced and manufactured plastic goods have contributed a significant amount to the climate crisis. These goods provide little meaning to consumers who buy them as cheap alternatives or quick solutions. Poorly made plastic toys with no playability beyond their often licensed appearances contribute little to no purpose to a child's development, usually ending their life cycle in landfills once they are no longer relevant. As there are no clear guidelines for creating a truly modular and adaptable toy system in pursuit of sustainability and playability, toys must be able to adapt to children as they age to provide more value and to combat the unnecessary discarding of goods. General principles of modularity, material reduction, and product simplification can be utilized in conjunction with relevant guidelines to help create toys for children's development. To establish a set of rules for designing sustainable, modular toys, an approach must include knowledge of how to manage resources effectively, how to encourage creative play, and most importantly how to develop products that evolve with users.

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Chapter 1 - Introduction

1.1 Problem Statement

Cheap plastic goods are a primary source of waste in landfills (source), waste that we cannot afford as climate change continues to worsen. 93% of plastic production uses fossil fuels, and management of plastic waste contributes to 4% of global greenhouse gas emissions (OECD, 2023). Over-production of these goods contributes to consumer culture and a negative environmental impact. This problem can be seen in children's toys and is magnified by their limited life cycle use. There is an unfortunate abundance of poorly made plastic toys with little thought behind their design that more often than not end up being discarded. According to a study by Levesque (2022), "80% of all toys end their life cycles in landfills, incinerators, or the ocean...and toys make up almost 6% of landfill plastics" (p. 777). Often toys are created to sell the newest product, offering little to no value for children's development or enrichment and only encouraging unnecessarily short product life cycles. There are a lack of toys that simultaneously promote critical thinking and imagination in play and are made sustainably.

1.2 Need for Study

Material waste, especially plastic waste, is a tremendous problem in fighting climate change. Products designed to be discarded not only clutter our landfills but also our homes. Single or limited-use plastic products take up space with uncaring designs meant to be replaced upon the release of the next iteration. This problem is especially present in toys. These products, often cheap plastic, seem like they aren't made to be kept and treasured, but to be played with in the short term before the next shiny new toy is released. This leads to toys that are as harmful to the environment as they are unhelpful to fostering a child's development and creativity. To help alleviate the symptoms of climate change, combat excess consumerism, and encourage meaningful play, a system for creating long-lasting and fulfilling toys and toy systems is necessary.

1.3 Objectives of Study

The objective of this study is to develop a design approach for toys and toy systems that meet childhood development, sustainability, and industry guidelines. Toys created with this approach should be used for as many types of play as possible and have an extended lifecycle compared to the average product on the market. Additionally, the components should be replaceable and recyclable when possible. Through research on sustainability, these guidelines will be defined based on techniques for reducing material cost and use, how to extend product life cycles, and how to create an ever-evolving toy. The goal of these guidelines should be to extend the toy's lifecycle as long as possible, and to do so will be further defined by principles of modularity, open-ended play, and critical thinking.

1.4 Definition of Terms

- Emotional Durability: reduces the consumption and waste of natural resources by increasing the resilience of relationships established between consumers and products. (Chapman, 2009, pp. 29-35)
- Modular: constructed with standardized units or dimensions for flexibility and variety in use. (Merriam-Webster, n.d.-a)
- Obsolescence: the condition of no longer being used or useful; the condition of being obsolete. (Merriam-Webster, n.d.-b)
- Open-Ended: an activity or situation that does not have a planned ending, so it may develop in several ways. (Cambridge English Dictionary, n.d.)
- Planned Obsolescence: a situation in which goods are deliberately made or designed so that they do not last for a long period of time. (Cambridge English Dictionary, n.d.)
- Playability: the quality of easy and enjoyable to play (Cambridge English Dictionary, n.d.)
- Sustainable: capable of being maintained or continued at a certain rate or level. (Oxford English Dictionary, n.d.)

1.5 Assumptions

When developing guidelines for an ideal sustainable and continuously usable toy, it is assumed that the primary user group is children under the age of 18 who will play with the toys with various degrees of involvement and complexity. Adults may play with the toy but they will not be part of the design consideration. Modularity will allow the toys to become more complex with additional parts and later considerations. A modular system must be able to integrate with itself and not merely add on. For example, a Lego set can be combined with pieces from another to create entirely new builds, but an accessory for a doll that can potentially be added to any doll remains a simple accessory. Through the guidelines, it is assumed that the life cycle of newly created toys will be environmentally sustainable and help tackle climate change by reducing waste and materials use.

1.6 Scope and Limitations

Though the goal is to create toys made to last, the guidelines will not pertain to the collectibility of toys and will instead focus on their durability as it relates to playability. While toys may include electronic components, the guidelines will focus on toys that are physical and have little to no interaction with digital components, including applications or video games. Adults may be able to play with the toy and the toy or toy system may accommodate for an advanced level of critical thinking, but they will not be the target market. Material choice will be a factor, but because sustainable choices are still developing and newer, better options may be discovered, it will be secondary to the playability and continuous use of the toys. To analyze the impact of products, single figure Life Cycle Assessments will be completed, but will rely on public information on the weight and material of retail toys.

1.7 Procedures and Methods

I. Step 1: Preliminary Research

A. Procedure

1. Identify core elements of sustainability in toys

B. Methods

1. Research environmental impacts and life cycle analysis
2. Research philosophies of that inspire longevity of products
3. Research childhood development

II. Step 2: Market Research

A. Procedure

1. Compare toy systems and individual products based on market data

B. Method

1. Research multiple modular and multi-use toys
2. Research the primary manufactured materials
3. Determine accomplished levels of play functions and modularity

III. Step 3: Definitive Modularity

A. Procedure

1. Determine ideal level of modularity and multiple functions in a toy

B. Methods

1. Develop potential solutions for open ended and creative play
2. Research existing approaches to modularity

IV. Step 4: Develop Tool

A. Procedure

1. Create a comprehensive tool for adding modularity and multiple functions in toys.

B. Methods

1. Refer to research on modularity, open-ended play, and child development.
2. Using a traditional flowchart, streamline compiled research into an easy to understand decision tree for developing a toy design.

V. Step 5: Test Tool

A. Procedure

1. Create a toy from one of the defined toy categories to test tool.

B. Methods

1. Use traditional design methods to develop a concept for a toy design.
2. Use the developed tool to add to the newly developed toy design.
3. Prototype and evaluate the toy against market research.

1.8 Anticipated Outcomes

The development of this research will lead to a fleshed-out, novel approach for designing quality children's toys. The approach will help reduce material waste and encourage thoughtful design that contribute to overall sustainability efforts. While avoiding excess material usage, this approach should help designers create toys that incorporate engaging features based on principles of modularity and multiple uses that extend product lifespans. Toys created with this approach may seem simple at first, but through combination with each other and the imagination of a child, the toys should be able to be played with in a variety of ways. Through thoughtful use of material, imaginative design, and a variety of functions, toys and toy systems created with the final approach should be played with for as long as possible and be played with by many generations. The final approach will be developed to the point where they can be demonstrated through a toy design that meets researched criteria.

Chapter 2 - Literature Review

2.1 Need to Adapt

In terms of scope, climate change can be a difficult problem to understand. What is known with certainty is that the climate of the Earth is changing, at the very least in part, from man-made activity. It is an existential threat for younger generations who will be tasked with solving this issue. Action must be taken to “reduce emissions of greenhouse gasses by 50% by 2030 and to *net zero* by 2050 to have a reasonable chance of limiting global warming to 1.5°C.1” (Penty, 2020). In addition, with the acceleration of consumer culture, it is estimated that “In total, one third of all of the planet's resources have been consumed within the past four decades” (Chapman, 2015, p. 7). At this rate, it is estimated that both the world’s oil and natural gas will be consumed in the next 50 years (Lumley, 2024). With the impact of human consumption, industry’s current behavior cannot continue, as ultimately, “it is not the strongest species that survive, nor the most intelligent, but those that are most responsive to change. In resilience thinking, this innate capacity to absorb disturbance and accept change (rather than to defensively block it) is key to success” (Chapman, 2015, p. 56). Industry must adapt to climate change, but this cannot be done overnight. Designers have a special role in the industry in addressing this problem.

2.1.1 Responsibility of Designers

The Austrian designer Victor Papanek argued that industrial design was at the center of the environmental crisis, due to the “frivolities and excesses of design” and deep involvement in

consumer culture (cited in Clarke & Jackson-Beckett, 2020, para. 1). Papanek also believed design to be a “political instrument” and was focused on “a commitment to ecology, sustainability and responding to the needs of minorities and the so-called ‘Third World’, as well as creating and producing things employing the fewest resources possible” (cited in Scarzella, 2020, para. 1). He released several works including *Design for the Real World* and *The Green Imperative* encouraging designers “to seriously contemplate their role in facilitating social change in the face of accelerated consumer culture, political strife, and environmental depletion” (cited in Clarke & Jackson-Beckett, 2020, para 2). Many advocates have taken inspiration from Papanek’s works and have argued that with “vast cultural, environmental, social and economic implications, sustainability in design can and needs to be about something more than product turnover and profit margins” (Clarke & Jackson-Beckett, 2020, para 5). Papanek’s philosophy was that “Design doesn’t just mean giving something form, it’s a transformative tool that must take social and ethical perspectives into consideration” and that designers have a responsibility to weigh environmental factors in their work (cited in Scarzella, 2020, para 7). Even without environmental concerns, designers have a pressing urgency to learn to design without plastic when possible. Plastic is made from fossil fuels, making it inherently a limited resource that based on current usage will someday run out: “Will we really run out of materials or of oil and gas? The present prodigal use suggests that we might; reports have been written, starting with the famous Club of Rome report in 1972, suggesting that we will” (Ashby, 2010, p. 76). As plastic becomes scarcer it will eventually become financially unviable for its current uses because “As the natural resources of materials are consumed and ore-grades diminish, prices rise; the lower-grade uses become economically untenable and consumption falls” (Ashby, 2010, p. 76).

If creating products utilize a disproportionate amount of existing oil, then those who design those products are the ones with a responsibility to change consumption behaviors. Products can become static as consumer culture changes and “...one of the fundamental problems underpinning the consumption and waste of natural resources is that consumers continually evolve, whereas products are frozen in time” (Chapman, 2015, p. 84). To counteract these issues and put us on a more sustainable path, products, especially those made from non-renewable resources, must be designed to be long-lasting.

2.1.2 Balancing Business, Consumer, and Environment

Designers have a responsibility to attempt to balance creating quality products that generate revenues for businesses while conserving resources and energy. It is a tough task to conceptualize, but for the sake of consumers:

Rather than just managing resource intensity with conventional products, companies should keep in mind the “value” side of the equation, and try to design innovative, game-changing products that provide significant improvements in quality of life and/or quantum reductions in their environmental footprint. (Fiksel, 2009, p. sect. 6.2.1)

Products made to be thrown away are ultimately harmful to both customers and the environment. Reinforced by overconsumption, this problem is for designers to solve:

Changing trends, pushed by seductive advertising, reinforce the desire for the new and urge the replacement of still-useful objects. Industrial design carries a heavy responsibility here – it has, at certain periods, been directed toward creative

obsolescence: designing products that are desirable only if new, and urging the consumer to buy the latest models, using marketing techniques that imply that acquiring them is a social and psychological necessity (Ashby, 2010, p. 75).

The products designers create must be analyzed from a broader perspective because of the complex economic and environmental considerations. Three categories to conceptualize the complete picture are “Manufactured capital—industrial capacity, institutions, roads, built environment, financial wealth (GDP). Human capital—health, education, skills, technical expertise, accumulated knowledge, happiness. Natural capital – clean atmosphere, fresh water, fertile land, productive oceans, minerals, and fossil energy” (Ashby, 2010, p. 158). Balancing these resources may be difficult, but the pursuit is worthwhile so that product design may be long-lasting and contribute more good than harm. Reducing the impact and harm done in the pursuit of profit is entirely possible, and has been proven to be so for the last three decades. In 1999, the Dow Jones Sustainability Group Index was set up to track shareholder value in companies that integrate environmental and economic factors. The pilot analysis suggested that efforts to promote environmental sustainability do not have to come at the expense of competitiveness (Chapman, 2015, p. 10).

In certain cases, manufacturing with environmental considerations can often generate more profit than traditional methods. In 2008, Puma, the sportswear manufacturer, researched and developed ways to reduce their carbon footprint, eventually creating the “Clever Little Bag” packaging concept. In reducing their material usage in packaging, the concept was projected to save Puma money and resourced in a variety of ways, including: “~500,000 liters **less of**

diesel...consumed for shipping to the final point of sale” (Curran, 2012, sect. 15.5). These impacts and benefits should be weighed based on a designer or design team’s ability to realistically achieve their goals. So long as more sustainable solutions do not greatly sacrifice the intent or result of a designed product, they should be taken whenever possible to maximize the holistic benefits.

2.1.3 Material Usage

While the world shifts to sustainable methods, designers and businesses have to learn to balance output and revenue with being more environmentally conscious wherever possible. The use of recyclable material is important:

Driven by growing environmental awareness, both government and industry organizations have begun to specify more ‘environmentally conscious’ materials that have significant levels (25% to 100%) of recycled content. This is feasible to the extent that substitution of recycled materials with potential impurities is cost-effective and does not compromise the quality of the final product (Fiksel, 2009, sect. 8.2.1.1.2).

Plastic should not be completely discarded from use as it can be necessary for creating critical components or extremely durable or long-lasting pieces, but it should be avoided when possible. The dynamic of what materials can be recycled is complicated:

For example, metals are easily recycled, because they can be purified in a molten state. Likewise, paper, glass, and many other materials can achieve substantial levels of

recycled content. However, the situation is different with engineering thermoplastics. The cost of separating the individual components is high, and the thermo-mechanical properties associated with recycled resins developed from mixed waste can be significantly compromised (Fiksel, 2009, sect. 8.2.1.1.2).

Ultimately to maintain the integrity of the product's lifespan and to minimize environmental impact, designers must "utilize virgin materials only for critical components, and recycled materials for less demanding applications such as base assemblies" (Fiksel, 2009, sect. 8.2.1.1.2). It is difficult to assess concrete rules for designing with a material that is considered "imperfect" like recycled plastic but in *Materials and Design* (Ashby, 2010) there is an outlined general guide to do so:

There are some simple guidelines for designing with recycled plastics. Specify thicker walls or features that enhance rigidity in a design where increased strength must compensate for reduced strength in the material. Select applications where color is not critical – additional colorants can be added to mask the original color of the material. Use materials that are easy to recycle. Minimize the number of different polymers in a product – separating them at the end of life is difficult. Select materials that are in mutually compatible groups, e.g. polyolefins (PE, PP). PET, PVC, HDPE, and ABS are easier to recycle than most other polymers. To aid recycling, avoid materials that are difficult to separate such as laminates, fire retardants, and fiberglass reinforcements. Avoid polluting elements such as stickers that interfere with recycling, or glues. (p.168)

Ideally, following these guidelines and others will help close the loop of product life cycles, merging the end of life with manufacturing so the material is not wasted. New plastics should still be considered if necessary for the product as sacrificing durability for the sake of marketing the toy could have just as negative of an effect. According to Chapman (2015):

Many researchers are beginning to suspect that recycling provides an ethical "get-out-of-jail-free-card", which liberates consumer conscience and, in so doing, generates even more waste. Eco-design limits itself to an environmental technological approach and recycling is sometimes even an excuse for more rapid discarding. (p. 15)

The ultimate goal should be to create long-lasting and sustainable consumer goods, renewable and continuously recyclable goods should be prioritized, but if compromising the integrity of the design, new materials should be used so consumers do not preemptively dispose of the product.

2.2 Sustainable Strategies

There are many strategies for designing more sustainably. For the scope of this thesis, the strategies mentioned will primarily focus on how design may affect user behavior and product durability to directly increase a product's lifespan before it is disposed of. Based on the Okala lifecycle guide, this means the strategies within the finalized approach will be within 5, Reduced

Behavior and Use Impacts and 6, System Longevity.



Okala

Figure 1: Okala Lifecycle Design For: Wheel (White et. al., 2004)

2.2.1 Sustainability and Material Use in Toy Design

The problem of unnecessary consumption and disposal of goods, particularly plastic ones, is especially rampant in toys since “the toy industry is the most plastic-intensive industry in the world. Approximately ninety percent of toys purchased in the United States are made of plastic (‘Environmental Impact of Toys’)” (McGrew, 2023, p. 50). It is estimated that in the United States alone “for every one million dollars in revenue, forty tons of plastic is used” (McGrew, 2023, p. 50). Worldwide, Townsend (2023) estimates toys to be a \$90 billion industry, leading to an estimated “25 million tonnes of carbon (produced to manufacture plastic for the toy industry).” On top of this, “The effect that plastic toys have on the environment is twofold; they are harmful in both their production as well as in their disposal” (McGrew, 2023, p. 50). The

disposal of toys is widespread with "nearly 80% of all toys end[ing] their life cycles in landfills, incinerators, or the ocean... and toys make up almost 6% of landfill plastics" (Levesque, 2022, p. 777). After disposal, plastic toys continue to wreak havoc on the environment. The best-case scenario for discarded toys is the landfill, where "greenhouse gasses are... released when plastic is decomposing" (McGrew, 2023, p. 50). According to the National Resources Defense Council, greenhouse gases may not be the worst effects of disposing of plastic. If incinerated, plastic can release "air pollutants such as particulate matter, which cause lung and heart diseases" and "toxic chemicals, such as PFAS and dioxins, which cause cancer and other health problems" (Rosenberg, 2021). The impacts that plastic production and disposal have on the environment and society is incredibly high. However, it is easier said than done to phase plastic out of use from the standpoint of a designer. While alternatives remain imperfect, industry will continue to use plastic as there are scenarios that may still require it.

The use of plastic in toys seems like the obvious problem, making the solution seem to be to design out plastic from toys wherever possible. This would certainly have a positive impact, as a study by Robertson and Klimas (2019) tested three toys including a "plush dog with no battery, plush dog with a battery, and MarbleFrenzy™" (p. 2) and proved that out of the three, "MarbleFrenzy™ had the highest Global Warming Potential...due to its plastic" (p.7). This coupled with the comparison of the two stuffed animals, which found that due to the plastic of the battery casing as well as the additional synthetic fiber needed to cushion the casing, meant that "the plush dog with a battery has a much larger impact from the higher amount of plastic in the dog's battery pack casing." Therefore, Robertson and Klimas (2019) concluded "that the plastic components resulted in the highest impact material overall" (p. 7). Lowering plastic

consumption is certainly a step in the right direction as “toys made of materials other than plastic typically have a lower carbon footprint than those made of plastic materials” (McGrew, 2023, p. 55). However, abandoning plastic will not solve the issue of unnecessary and frequent toy disposal.

Even well-designed and well-intentioned toys may end up in a landfill. The perception of durability may matter as much as the physical durability of toys. Metal and wood are both, on average, less harmful to produce and maintain their integrity longer than some plastics, but these materials cannot be handled the same way plastics can. Toys that are otherwise sustainable in their material usage and production may still be discarded rather than donated since “plastic toys can also usually be easily cleaned and sanitized, which may not be true of some toys made of other materials such as fabric or wood” (McGrew, 2023, p. 51) which may make second-hand owners wary of buying used. Plastic has a perception of durability, and the right kinds are. As mentioned earlier, some plastics are durable enough to avoid a severe negative carbon impact, so long as they are not thrown away. LEGO, for instance, is made from Acrylonitrile Butadiene Styrene (ABS), which is incredibly durable. LEGO’s durability allows it to be sustainable in the sense that it has an increased longevity compared to most plastic toys, and can easily be passed down second-hand to be played with continuously because of its fully modular system. Designers prefer plastic because it “is an inexpensive, lightweight, strong, and durable material, making it an ideal choice for producing toys” (McGrew, 2023, p. 51). Plastic can also be utilized to create much more complex toys than wood or metal, as well as being “typically much more affordable than those made of other materials, making them more desirable to many consumers” (McGrew, 2023, p. 52). When it comes to the functionality of the toy, using more sustainable materials may

affect the physical durability of the product, and “Designing toys for landfill disposal is not necessary to increase enjoyment or play. Toys with extended lifetimes as hand-me-downs were preferred in child care settings due their durability” (Levesque, 2019, p. 790). Buyers are unlikely to purchase sustainably made products if they do not believe their child will be engaged for a long enough period to justify the cost, especially if the buyer is in a childcare position where durability and longevity are paramount.

Toy design has fallen into the especially dangerous practice of planned obsolescence. According to Levesque et al (2022):

This started in the toy industry around 1994 when Mattel began using a “rolling mix” where they would release slightly changed products, such as Hot Wheels™ or Barbie, twice a year (Johnson, 2001). This was done to increase sales: “If customers saw new products every time they went to the store, they were more likely to buy.” (pp. 789-790)

Ultimately this overconsumption and overproduction can contribute more to environmental waste than a high-impact toy that is continuously passed down. Motivated solely by the desire to own their favorite character or fit in with what is contemporarily popular, “Children cannot be expected to understand the consequences of such consumer behavior in relation to the environment, as they put pressure on their parents to purchase toys” (Gulden, 2021, p. 1). The responsibility of avoiding wasteful practices in toy design must fall on the designer to help parents and caregivers more easily make sustainable purchases. Designing a toy based on a popular franchise should not excuse failing to design it in a durable way. Poorly designed toys will likely end up contributing to the current majority of toys that end their life in a landfill

because “when toys are designed with a short life span, their environmental impact will be higher since impact is apportioned over the toy's lifetime” (Levesque, 2022, p. 790). As such, “sustainable toy purchasing can take on many forms including purchasing second-hand, hand-me-downs, purchasing durable toys, or recycling” (p. 778). The core problem of toys ending in landfills goes beyond material and rather lies in how the toy was intended to be received by consumers.

Toys should be designed to be played with and last, not to be discarded upon any inconvenience. Play with a toy must be continuous and provide multiple levels of engagement. “Nearly one-third of parents have admitted to throwing away toys that were in good working order because their children do not play with them any longer” (McGrew, 2023, p. 52). Simplicity or over-complication can lead to boredom or frustration. With this in mind, toys should also be designed so that there are little to no inconveniences within their lifespan. The design of toys must visually communicate that they are made to last since “the perception of toys as temporary due to some toys being designed to fail or break due to material choice (Satyro, 2018) may also play a role in the constant consumption and purchase of toys, further increasing impact” (Levesque, 2022, p. 790). Material choice plays a vital role in the longevity of a toy's product lifespan, as it can impact how the toy can be played with and cared for by the child and parents. A toy must be durable both physically and emotionally so that its purchase is not made lightly by a consumer and so that its environmental impact is as low as possible, avoiding disposal for as long as possible.

2.2.2 Necessary and Fulfilling Products

While it is important to consider how products are designed, to design sustainably and prevent products from being unnecessarily discarded we must analyze why products are designed. A product can be manufactured in a completely environmentally friendly way, but could still be thrown away by an unsatisfied consumer. The quality of a product must be maintained long after it is produced, and a source for cheap and quickly made products is mass production:

Mass production now supplies products to a far larger market and in far larger numbers than in the earlier days of craft-based design, when few could afford them. In this sense, mass production has enhanced the quality of life, but in others, it can diminish it. Our environment is enhanced by-products that satisfy us. By contrast, if products create expectations that are not fulfilled, add nothing to (or even detract from) self-esteem or sense of place in society, or give no sense of satisfaction, then the quality of life has suffered. (Ashby, 2010, p. 21)

Instead of quickly made goods designed to be bought and thrown away when no longer convenient, products should be designed to provide long-lasting benefits to consumers for them to be sustainable and, perhaps more importantly to our profession, of a good design. According to Penty (2020):

To achieve this, product designers need to shift their emphasis from creating objects to *meeting real needs*. The change of focus from the physical object to satisfying physical

and emotional needs through the experiences, narrative, and meaning that products can create is liberating for designers. This allows more holistic and therefore sustainable thinking that takes into account the wider context and interrogates the need. (p. 5)

The goal of a well-designed product should be to address a problem or need in people's lives and continue to meet that need for as long as possible. Designs should not, however, be only utilitarian; otherwise consumers who are satisfied with a product's practicality may still dispose of it in favor of a less practical or less sustainable product that provides a more fulfilling experience. The goal is for the product to last as "a well-designed product can outlive its design life by centuries, and – far from becoming unwanted – can acquire value with age... People do not throw away products for which they feel emotional attachment" (Ashby, 2010, p. 76). As products successfully create fulfilling emotional experiences, this creates attachment. Further emotional attachment can create a type of durability within a product as owners project memories and positive experiences the product has provided. This concept is called emotional durability.

2.2.3 Emotional Durability

To further prevent the untimely discarding of toys, it is important to create an emotional attachment and develop emotional depth within the product. Reducing material impact is vital, but does not ultimately curb consumption and waste. With emotionally durable design, "the ultimate aim is to reduce the consumption and waste of resources by increasing the durability of relationships between consumers and products" (Chapman, 2015, p. 21). The durability of a

design extends beyond the physical nature of the product and into the mental and emotional state it creates within a user. According to Chapman (2015), “...durability is just as much about desire, love, and attachment as it is fractured polymers, worn gaskets, or blown circuitry” (p. 13). He continues, claiming that overly focusing on physical durability leads to an oversight of what makes a product sustainable and long-lasting:

Few would contest that the principal endeavor of durability is to optimize the functional life of objects. Thus far, the creative methodologies addressing design for durability are monist, single-minded approaches that attend to the physical, cosmetic, survival of artefacts. In these somewhat superficial scenarios, durability is distinguished purely by a product's physical endurance, whether cherished or discarded; engineers therefore slap each other's backs in triumph as fully functioning hairdryers emerge from a five year landfill hiatus. (p. 62)

A plastic toy will have the same impact in production whether designed durably or for disposal, but “Duration of play, however, is an important component of toy impact for multiple reasons. Toys that have limited use can be quickly discarded. While this does not change the impact of these toys, it can lead to an increase in toy purchasing” (Levesque, 2019, p. 790). Creating an emotionally durable toy will mitigate the impact of toy purchasing made to replace a now boring or broken toy. The three main methodologies Chapman proposes to create emotional durability are by creating attachment, designing fuzzy interactions, and ensuring repairability.

As discussed earlier, attachment is what prevents even useless products from being disposed of. Many things can cause attachment to fade, whether it be the product breaking, or falling out of style “...waste is nothing more than symptomatic of a failed user-object relationship, where insufficient empathy led to the perfunctory dumping of one by the other” (Chapman, 2015, p. 25). Toys should create as much play and as much fun as possible for a child, with the express intent of a lasting positive experience:

As toys influence play, play enabled by a toy affects the degree of attachment toward the toy. The child connects experiences that emerge by play, throughout all stages of ownership of the toy, to the toy itself. Thus, the toy’s ability to elicit experiences is connected to how long a person hangs on to it, given that one does not replace products that are treasured. Even though people have the propensity to favor new things, strong feelings of attachment toward a toy make new products offered on the market less tempting. (Gulden, 2021, p. 2)

There are two methods to elicit attachment in a toy according to Gulden (2021). One is through a transmedia storytelling (TS) connection which involves a “...complex toy-media platform presents a play theme through, for example, movies, cartoons, or games” (p. 1). This type of representative toy can create an immediate attachment through recognition of a child’s favorite character or series, but relies on pre-existing marketing campaigns:

For example, a Pokémon figure can be recognized in the store because of the cartoon shown on TV or by a digital game; consequently, it will stimulate purchases among

children who have many of these figures already and those who are reminded about the cartoons or games because of the new experience in the shop. Thus, the marketing strategy involves the designing of an experience related to the product for the pre-purchase phase and the point of purchase phase of product ownership. (p. 4)

Using previously generated attachments from the stories or characters, a toy can create an additional layer of attachment within a child upon the moment of purchase, relying on a desire to emulate and collect tokens from the media. So long as a child is invested in the theme and the media it is from, Gulden (2015) states that:

Play themes presented by a TS-toy do not necessarily hinder the imagination or fantasy, as mentioned earlier. Children love repetition and predictability. For example, they often want to listen to the same book hundreds of times, perhaps out of feelings of safety and stability or as a starting point for imagination. It is likely that this is the same for toys. (p. 7)

The limitation of this method is its potential staying power as the child grows. So long as they are invested in the media, they should be invested in the toy, but this relies on the media itself not falling out of favor with the child or culture as a whole. As Chapman (2015) explains, “Simply put, when the products we own reflect desirable and up-to-date reflections of our existence, they get to stay, while products that do not, do not” (p. 49). Additionally, while transmedia storytelling toys have many benefits, there are drawbacks: “Although toys that utilize TS often demand quite a bit of learning, planning, and skills, they also prescribe how to play, which theme

to play within, and consequently the child's play experience" (Gulden, 2021, p. 1). Gulden states there is room for creativity and a feeling of personalization with toys, albeit limited:

Providing opportunities for the user to alter a product during the whole ownership has been suggested as a way of strengthening the feelings of CPA [Consumer Product Attachment]. Toys can often be physically altered. However, the associated theme that comes with the toy, such as Star Wars or Harry Potter, is often permanently attached to the physical toy or its parts, which hinders the making of new play themes. (p. 2)

Because of the defined play theme, these toys potentially limit deeper emotional attachment through customization and self-definition: "Although transmedia storytelling acquires attention and activates children through the available different platforms of play, it seems to hinder the personalization of play themes, presumably because the strength of the theme goes beyond guidance" (Gulden, 2021, p. 9). The opposite of this method then, is to allow the toy to exist in its own right and allow the child to develop attachment through use.

To create attachment in a toy without using transmedia storytelling, the toy must be open-ended for a child as "...it is suggested that the personalization of play themes enables the child to create personal experiences, a factor that contributes to a higher degree of pleasure, which can delay the child's desire to replace the toy" (Gulden, 2021, p. 1). Open-ended toys allow for a child to create an impression of the object that does not stem from pre-existing stories, but rather the stories the child creates themselves. The best examples are the simplest: "Lego and fire engine toys have been a success for decades, possibly because they motivate the

creation of personal experiences” (Gulden, 2021, p. 7). Chapman (2015) argues that a product with limited initial definition will prolong its lifespan as the user determines its meanings through use, whereas “the brutal discarding of fully functional products is actually catalyzed by excessive usability, which leads to the exclusion of error and accidental discoveries” (p. 83). Allowing for a toy to be open-ended and flexible to several play themes, especially if that toy can be later repaired or modified, promotes attachment. If the best way to create a long-lasting attachment with a toy is to provide personal, emotional experiences, then the best method is to add personalization to the toy. As Gulden (2021) mentions, “The theoretical study of these observations indicates that the degree of personalization of play themes relates to resistance, recognition, creation of personal experiences, and a toy’s intellectual classification as factors of play” (p. 8). The ultimate goal of personalization is to encourage creative thinking that may otherwise not be possible within the confines of a media theme. Toys that allow for this open-ended attachment will create a deeper connection with a child based on the idea that:

...a user will become more attached to products that stimulate on a cognitive, emotional, relational, perceptive, and imaginative level. The activation serves to facilitate the user to produce personal experiences and therefore memories. Moreover, the product will serve to convey memories about prior salient happenings and therefore represent meaning for the user or owner, and accordingly represent a higher degree of [Consumer Product Attachment]. (Gulden, 2021, p. 4)

Straightforward and confined products are lacking according to Chapman (2015) because “...it is quite possible that products designed in this way are simply too predictable, and thus, are

incapable of holding our interest over any great length of time” (p. 83), whereas products that stand independently can lead to “Deeper and more intense bonds... forged between users and objects when products portray a perceivable sense of consciousness” (Chapman, 2015, p. 144). When a product is capable of adapting, it has a sense of independence, and, “In doing so, a world of richly diverse, amorphous, and less predictable interactions unfolds, enabling a far richer and more enduring engagements from within the regular confines of material culture” (Chapman, 2015, p. 144). The same culture may cause stagnation in other toys. Fuzzy interactions and open-ended design for a toy can be introduced in several ways such as modularity, which is discussed further.

Being able to maintain an object is an important factor in ensuring emotional durability and attachment. This goes beyond the simple matter of making the product durable, but easy to repair, when, not if, the durability is compromised. Creating a product that is easy to fix encourages consumers to repair rather than replace, such as:

In the case of the hammer with the wobbly head, repair is a fairly straight-forward process, and this may in fact be why so many of us are happy to keep the hammer we have and fix it should it fail, thus making the return journey from present-to-hand (broken, and visible) to ready-to-hand (working and transparent). (Chapman, 2015, p. 109)

This can be especially true in toys, which are prone to emotional attachment due to the aforementioned reasons. This concept of repairing a sentimental object because of the emotional value it holds is even named after a toy, “the teddy bear effect”:

Swiss industrial analyst Walter Stahel discusses certain narrative phenomena in terms of their "teddy bear factor." Despite the toy market's daily introduction of newer and fluffier bears, teddies the world over are faithfully loved, cherished, and adored for literal decades on end. When an arm falls off, it is sewn back on; if an eye becomes loose, it is fixed. Most adults - if pushed - will confess to still owning at least one bear: a bear with a gender, name, and age. More importantly they will share a rich history with the bear, elevating its often worn-out physical body to an irreplaceable plateau that is safely beyond the reach of obsolescence and waste. (Chapman, 2015, p. 121)

The goal should be to create this effect in every toy. A desire to uphold the physical product, whether out of nostalgia and the want to keep it forever, or maintain it for its future user. All objects will degrade with time, and if a component is not able to be replaced within the product completely, Chapman (2015) argues one must consider the “patina” of its materials, since “...the social values affixed to the aging of material surfaces are intensely complex. Natural-fibre carpets age badly while pinewood floors are practically at their worst when new; and leather-bound books improve like fine wines...” (p. 136). The ease of maintenance is essential. Several products can be repaired, but the time and energy to do so must be valued as less than the cost of replacement. For instance, in the case of certain types of clothing, “Skilled individuals will carry out repairs and alterations to clothes for you, often while you wait. But oddly enough,

very few people engage with this type of service, preferring instead to dispose and repurchase” (Chapman, 2015, p. 165). With finer items like an expensive, brand name Barbour jacket, the company will do the repairing and maintenance for the customer; “If your Barbour jacket loses its finish, or gets torn on a barbed-wire fence, you return it to Barbour who will re-wax it and repair the rip” (Chapman, 2015, p. 165). This allows for the easy upkeep of a product with an existing attachment, as well as the feeling of gaining something new, “...six weeks later, your old jacket arrives through the mail, but it kind of feels like a new jacket - it's reborn” (Chapman, 2015, p. 165). This may replace the positive emotions of buying something new.

2.2.4 Modularity

Design must shift away from overproduction and overconsumption, especially since in the past it has “been directed toward creative obsolescence: designing products that are desirable only if new, and urging the consumer to buy the latest models, using marketing techniques that imply that acquiring them is a social and psychological necessity” (Ashby, 2010, p. 74). Instead of creating products that are created to be thrown away, products must be created to not only last but adapt to the users and to the times.

A potential solution for preventing the unnecessary discarding of products is to create products that adapt across their lifespans. Products that change with time and allow consumers to replace parts instead of the whole create a unique opportunity:

When your house no longer suits you, you have two choices: you can buy a new house or you can adapt the one you have got, and in adapting it you make it more personally

yours. Houses allow this. Most other products do not, and an old product (unlike an old house) is often perceived to have such low value that it is simply discarded. And that highlights a design challenge: to create products that can be adapted and personalized so that they acquire, like a house, a character of their own. (Ashby, 2010, p. 78)

Modularity is a strong tool to combat unnecessary waste and production. As mentioned earlier, “People do not throw away products for which they feel emotional attachment” (Ashby, 2010, p. 76) and the responsibility of designers must be to create products that have that emotional attachment potentially throughout multiple lifetimes. Personalization provides a direct method for creating adaptable products and “In recent years, products such as customized Everyday Carry (EDC) gear, Apple Watch’s removable watch bands, and handcrafts have seen great demand as consumers increasingly crave individuality” (Li, 2024, p. 220). This personalization and adaptability are added through product modularity. Li (2024) defines modularity as “...the quality of a one-to-one relationship between functions and components, and interfaces standardized such that one component may be interchanged for another” (p. 218).

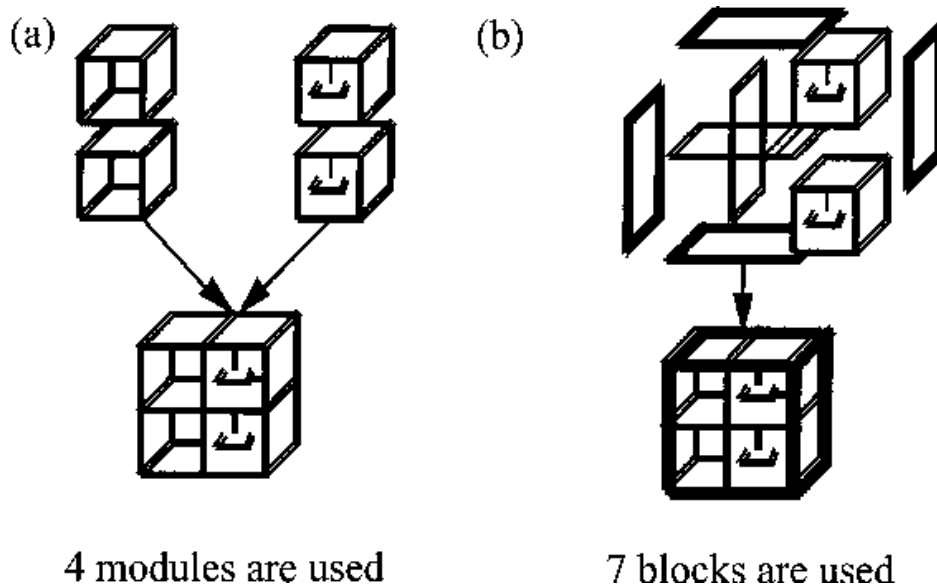


Figure 2: Two Designs of a Piece of Domestic Furniture. (Huang, 2000)

Modularity is named after the subcomponents that make up modules. Modules can be more accurately defined as “...part of a product, but with self-contained functionality. Here, a module could be seen as independent but also part of a whole set with a global function” (Hvam et al., 2017, p. 3). However, a product can be made of modular components that are not considered modules, but instead referred to as blocks. Huang (2000) defines a block as “is a collection of components that implement some functions of the product” (p. 150). If the component is singular in its function and limited in subcomponents, it remains a block; however, if the block is made from “a collection of interchangeable components that implement similar functions...the block is called a module” (Huang, 2000, p. 150). Separating these recyclable materials cannot prevent unnecessary consumerism, but modular products that are made to be partially replaced only when needed can achieve that goal.

2.2.5 Life Cycle Assessment

A life cycle impact assessment is an objective way to measure the environmental impact of a product based on its manufacturing, materials, and lifetime use. The assessment is primarily made up of a bill of materials, the total inventory, a characterization, a normalization, and a weighting. The bill of materials “quantifies the materials of the product itself and the packaging, energy and extra materials required while in use, and transport during its entire lifecycle” (White, et al., 2004, p. 44), meaning the total bill includes all materials the product consumes including the fuel sources required in production and distribution. The inventory “multiplies the inputs in the bill-of-materials by the specific chemical emissions (to air, water, or soil) and land-use factors and resource depletion values that have been collected for each type of material process” (White, et al., 2004, p. 44), which allows for a specification of what kind of emissions are produced. The inventory process is generally more complex and difficult to fully without internal data.. Characterization “converts the inventory emissions into environmental impacts” (White, et al., 2004, p.44), and is aided by defined, scientific formulas. Normalization is the process of scaling the impacts to a more relative reference based on consumer data. Weighting simply “scales impact categories according to priority of significance” (White et al., 2004, p. 44) allowing for a more comprehensive view of the assessment. These factors combined allow for a holistic view of the impacts created over a single product's lifespan, and when sourced from original manufacturing data, can create a full-scale LCA.

A full-scale LCA, however, requires complete inventory data. This can be difficult for a designer or small design team to acquire independently. For individual use purposes, a single

figure LCA can be used. The data from a single figure LCA “...should not be used for public claims about environmental performance...” (White et al., 2004, p. 45) but provides a baseline score for designers to compare and analyze a product’s environmental impacts. To scale down a full-scale LCA to a single figure LCA, a system boundary must be established to “explain what is not being evaluated in the product system” (White et al., 2004, p. 45). Next, the product lifetime value must be estimated to represent the total number of hours the product will remain functional. After this, a functional unit value should be established to allow a “comparison of disparate products per unit of delivered service” (White et al. 2004, p. 45). This value allows for an understanding of the service a product provides as well as the level of quality. Following step 1 of the full-scale LCA, a bill of materials is completed next. This often requires disassembling a product to understand each component’s weight, material, and manufacturing process. With all of the data collected, a single figure LCA can be performed.

Example of the LCA process



BUTTONS



ZIPPER

We compare the impacts of 12 buttons versus a zipper on a jacket to demonstrate how the assessments are performed.

STEP 1 > Define lifetime, functional unit & system boundary

The jacket with the zipper is worn more often, and it wears out faster.

Lifetime Buttons 150hr/yr x 6yr = 900hr
Functional unit impacts/100 hrs worn
System boundary excludes jacket, thread, washing

Lifetime Zipper 190hr/yr x 4yr = 760hr
Functional unit ditto
System boundary ditto

STEP 2 > Make bill-of-materials

Next compile the bill-of-materials for the fasteners:

PLASTIC BUTTONS

Materials polycarbonate(PC) 0.050 lb
 package paper 0.025 lb

Manufacturing injection mold 0.050 lb
Electricity sewing machine 0.042 kw-hr
Transport truck 0.067 ton-mi
Disposal landfill

**Brass is made of 63% copper, 27% zinc*

BRASS* ZIPPER

Materials zinc 0.025 lb
 copper 0.043 lb
 cotton tape 0.044 lb
 package paper 0.039 lb

Manufacturing machining 0.068 lb
Electricity sewing machine 0.063 kw-hr
Transport truck 0.103 ton-mi
Disposal landfill

STEP 3 > Calculate estimated impacts

INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS
			Okala03 millipoints
PC	0.050 lb	180/lb	9.00
paper	0.025 lb	27/lb	0.68
inj. mold	0.050 lb	11/lb	0.57
sewing	0.042 kw-hr	20/kw-hr	0.83
truck	0.067 ton-mi	9.7/t. -mi	0.65
landfill PC	0.050 lb	1.6/lb	0.08
landfill paper	0.025 lb	5.3/lb	0.13
TOTAL IMPACTS/LIFE BUTTONS:			11.94

INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS
			Okala03 millipoints
zinc	0.025 lb	81/lb	4.05
copper	0.043 lb	160/lb	6.88
cotton	0.044 lb	140/lb	6.18
paper	0.039 lb	27/lb	1.05
machine	0.068 lb	1.2/lb	0.08
sewing	0.026 kw-hr	20/kw-hr	0.52
truck	0.103 ton-mi.	9.7/t. -mi	0.99
landfill zinc	0.025 lb	0.25/lb (est.)	0.006
landfill copper	0.043 lb	0.25/lb (est.)	0.01
landfill paper	0.039 lb	5.3/lb	0.21
TOTAL IMPACTS/LIFE ZIPPER:			19.976

Next, we calculate the impacts per functional unit and round to two significant figures:

$$\text{button impacts} \times \frac{\text{functional unit time}}{\text{lifetime}} = 11.94 \times \frac{100 \text{ hr}}{900 \text{ hr}} = 1.3267 = \frac{1.3 \text{ Okala03 millipoints}}{100 \text{ hours buttons are worn}}$$

$$\text{zipper impacts} \times \frac{\text{functional unit time}}{\text{lifetime}} = 19.976 \times \frac{100 \text{ hr}}{760 \text{ hr}} = 2.6284 = \frac{2.6 \text{ Okala03 millipoints}}{100 \text{ hours zipper is worn}}$$

The buttons have roughly one half of the environmental impact of the zipper per functional unit.

ASSESSMENT: module fourteen • 47

Figure 3: Example of the LCA Process (White et al., 2004)

This simplified equation provides a simple, measurable number of a product's lifetime impact.

To reduce the impact per product two important changes can be made, using lower impact

materials or increasing the product's lifetime use. The longer a product is able to be used, the less

impact it will have per functional unit.

2.3 Toy Design

While standard product design methods are useful, certain factors must be considered to truly make a successful toy. Tactics like emotional durability must be further specified to apply to an object meant to be played with. Modularity becomes more than a convenience for product adjustment by being incorporated to the use of the toy itself. Most importantly, the target demographic of toys is already determined, with designing for children having its own unique considerations.

2.3.1 Childhood Development

Maria Montessori is attributed with saying “play is the work of a child.” This is not simply because children spend their time playing, but because play is essential to a child’s development and learning. To an outsider, play is not considered a serious task, yet:

The fact that play is not ‘serious’ in this setting does not mean that play is not perceived as serious by the participant; on the contrary, a player can engage ‘intensely and utterly’.

Within the boundaries of play, a player would indeed ruin the game without serious intentions.” (Gulden, 2021, p. 3)

Children can take play very seriously, and for good reason. There are several ways play helps children grow, including contributing to “the development of cognitive, motor, and psychosocial, emotional, and linguistic skills” (Cetin Dag, et al., 2021, p. 414). Toys and games help encourage play, which can encourage physical activity according to Cetin Dag et al. (2021): “If the physical activity includes playing, its effectiveness increases even more and children do it with great

pleasure” (pp. 414-415). In young children, physical play helps to develop fine motor skills such as “carrying, grasping, writing, drawing geometric pictures with a pencil, cutting paper with scissors, playing with dough and sand, stringing beads, and eating suitable foods with a fork” (Cetin Dag et al., 2021, p. 415). These activities can be mimicked or recreated with the help of representative toys, and help children accomplish the real thing. Children can also develop emotional skills during play, such as respect, sharing, and cooperation (Cetin Dag et al., 2021, p. 414). As children age, the types of representative play can evolve and be used as an outlet to grapple with negative emotions and translate them into something more manageable, according to Cetin Dag et al. (2021):

During play, children not only reveal feelings that make them happy but also reveal their fears, jealousy, and negative emotions that they cannot cope with. They learn to deal with their fears, to control their jealousy, and to control their emotions. (p. 417)

The skills and complexity of development change as children age; therefore the types of play engaged with to encourage that development must change as well.

While each child is unique and no person fully grows in the same way or at the same rate, childhood development can be roughly divided and categorized. Jean Piaget, a Swiss psychologist, divided children’s cognitive development into four such categories:

- Sensorimotor. Birth through 2 years old
- Preoperational. Toddlerhood through early childhood (2-7 years old)
- Concrete operational. Ages 7-11 years old
- Formal operational. Adolescence through adulthood, 12 years and older

(Cited in Ansorge et al., 2024, sect. 2).

Piaget believed that while some children may reach these stages at different times and remain in them at different lengths, the sequence remained the same and no child could skip one (Ansorge et al., 2024, para. 2). For play, Piaget considered the first three stages to be where the majority of play occurs in life, as the fourth is a transitional stage into adulthood where any further cognitive development is pursued through intellectual learning (Ansorge et al., 2024, para. 6). According to Richards et al. (2022), “Piaget... long ago proposed three broad stages in the development of play— sensorimotor play, symbolic play, and games with rules, which are widely accepted as the standard progression of play complexity across childhood” (p. 2). These three categories are broken down as follows:

Sensorimotor play lasts throughout infancy and early toddlerhood and entails manipulating objects for exploration (e.g., mouthing, fingering, hitting, shaking objects). During the second year, children enter into symbolic play, or play that is more abstract in nature. In imaginary play, a toy can represent a real-world object, and gestures can represent real-life actions. Symbolic play peaks in prevalence around 4 years of age, starting to decline after age 7 (Lillard, 2015). Between 7 to 12 years of age, children begin to set their own a priori rules and regulations, and engage in games with rules, such as board games or basketball. (Richards et al., 2022, p. 2)

As the type of play children engage with increases in complexity, so too must the complexity of the toy increase. Children will gravitate toward toys designed for them, and according to a study by Richards et al. (2022): “...children were more likely to fully utilize age appropriate toys than toys appropriate for older children...” (p. 11). A toy that would be designed for multiple age groups therefore cannot start as complex and must have a way for further engagement to be

added, not removed. On the basic types of engagement with toys, children tend to have an easier time working backward rather than forward:

Considering only the motor and cognitive demands of toys, children of any age should be able to use toys as intended that were designed for younger children. However, toys suitable to younger children may be less interesting to them than age-appropriate toys, and children may lose interest before they fully utilize them. (Richards et al., 2022, pp. 4-5)

The goal of a toy design should be to engage with the current abilities of the child it is targeted for, with the potential baked in to grow further as a child ages. Each stage of childhood development must then be understood in greater detail so that a toy design can be properly accommodating for a given age.

The sensorimotor stage of childhood development happens generally between birth and 2 years old, where infants interact with their world only in the immediate environment and are still learning to engage with their senses and motor skills (Ansorge et al., 2024). Infants are learning in every way they can, still figuring out the way the world works: “They’re constantly experimenting because they don’t yet know how things react. They shake or throw things, put things in their mouth, and learn about the world through trial and error” (Ansorge et al., 2024, sect. 3). Between five and eight months is when children start to develop object permanence, the ability to remember an object exists even when not in sight (Ansorge et al., 2024, sect. 3). Toys designed for children at this age should encourage the development of early, rudimentary motor skills as well as focusing on more basic activities relying on association rather than memory. The end of this stage usually starts around 18 to 24 months old when “infants reach another important

milestone -- early language development -- a sign that they are developing some symbolic abilities” (Ansorge et al., 2024, sect. 3). This is when play becomes more complex and abstract in the preoperational stage.

The preoperational stage takes place between 2 and 7 years old when children begin to think symbolically, now understanding and creating meaning between representations and real world people, objects, and ideas. Now that a child has the ability of object permanence, they are able to imagine concepts they understand without having to look at them. Imitation play, pretend play, and creative play start as children further develop their ability to imagine and not only recreate their world but add to it with their own input. Children in this stage may have difficulty “understand[ing] that others think differently from them or see things from another person’s perspective” (Ansorge et al., 2024, sect. 4) and should be encouraged to continue their own creative expression in play while being reminded to be considerate of others before they can grasp this concept themselves.

The concrete operational stage is when children start to develop logical reasoning between the ages of 7 and 11 years old. Children in this stage can understand conservation, “that things remain the same despite existing in a different form” and reversibility, the idea “that things can return to their original state unchanged.” These skills coupled with understanding class inclusion “group[ing] objects based on shape or type” and object relations, and the ability to “use logic to perceive and organize a series of gradually changing items, such as arranging objects by size” (Ansorge et al., 2024, sect. 5), allow children to engage in more complex play, transforming and changing their toys into something new. These skills also allow for more

refined thinking, with children able to start engaging with more complex ideas, and able to build their own creations with meaning and purpose.

Around 11 years old or older, children begin the final stage of cognitive development called the formal operational stage. From this point on, the way they play may not independently develop further, but the way they perceive and understand the world will. Through further intellectual development, children in this stage can now “use symbols related to abstract concepts, such as algebra and science [and can also] think about abstract relationships and concepts such as justice” (Ansorge et al., 2024, sect. 6). The understanding of these abstract concepts allow for more engaging play with STEM toys, and more complex toy mechanics or game rules. These developing concepts should be reinforced with play that promotes abstract thinking and is challenging enough for a child to not consider the play tedious or meant for younger children, as children in this age start to become more self-conscious.

Toys may be easily targeted to any of these defined categories using the general recommendations and other established resources for each age. With these categories in mind, the challenge becomes to design a toy in a way capable of changing with these stages of development. As a child’s development scales in complexity, so too should their toys by adding more complicated features and components.

2.3.2 Modularity in Toy Design

A particularly strong direction for creating toys that enhance children’s development is to incorporate modularity. Modularity in toy design could potentially allow a toy to start simple, aimed at children in the first two stages of play, then evolve with the child and become

increasingly detailed or complex as new components are added. Puzzle and building toys, two categories that generally have the design groundwork to have interchangeable components, have been found to help with coordination and critical thinking (Tengfei, 2016, p. 2), and modular toys especially have been “highly regarded by experts and scholars for its entertainment and puzzle functions...[and seen] as one of the most effective learning tools” (Zheng et al., 2019, p. 243). Modular toy design has also led to one of the most famous toys in LEGO, celebrated as “...easily a gold standard among toy designs, given its ability to expand, be repurposed, and bring forth great developments to children through free, shared, or fluid play” (Li, 2024, p. 217). Based on the above definitions “a module has to possess a considerable amount of functionality – more than the product or flow it makes up” (Hvam et al., 2017, p. 3); therefore, despite still being a modular toy, “LEGO bricks cannot be considered as modules even if they permit construction by combination, because by themselves, they only have limited functionality” (Hvam et al., 2017, p. 3). What makes a toy modular? According to a study by Zheng and others (2019), modular toys must:

...have the following three characteristics: a. Unit modules have one or more forms, and the functions between modules are the same or have some connection with each other b. Connect the unit modules utilizing plugging, embedding, splicing, fastening, gearing, and assembly; c. The game process is reversible and the assembled toy can be taken apart and used repeatedly. (p. 243)

A toy that can be assembled and reassembled over and over allows for a unique opportunity to design a toy with multiple uses. The toy can potentially be diversified, adding new features and play abilities “as the technology develops, with more stable and more diverse functions, which

not only makes the toy have more combinations of functions. It also gives the toy the possibility of self-sustaining development” (Zheng et al., 2019, p. 244). Li (2024) further defines types of modularity within toys based on the level at which components are interchangeable:

With the criteria specified, the following extremes, together with a midpoint, define the three vertices on the first axis, the extent axis:

- Non-modular: The toy being built is of sole purpose and does not desire to be utilized in ways other than what it was initially designed for. All functions are being imposed on a single component, and there are no interfaces specified for module interconnections.
- Semi-modular: The toy possesses some extent of modularity, where some components are interchangeable or removable. The functions and components have a many-to-one relationship, and interfaces are specified for component swapping.
- Fully modular: Each component can be connected to any other component and each component has a single function; Interfaces are extremely important as components with no function overlap are typically hard to interconnect. (p. 218)

The level at which a toy can be redesigned and adapted should be decided based on how many opportunities a designer wishes to fulfill. Depending on how complex the toy is intended to be, what age range it is intended for, and how long the toy is meant to be kept around, a fully modular toy may not be a useful approach, as younger children will have difficulty understanding the component functions and how they are meant to interconnect.

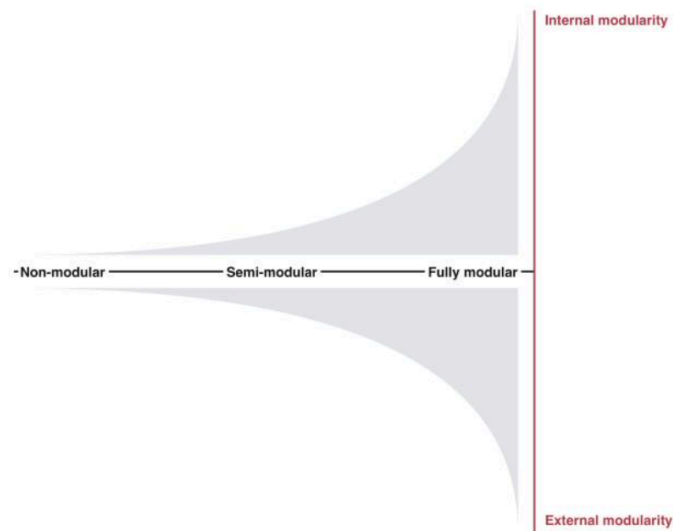


Figure 4: Modularity Graph (Li, 2024)

Another possibility of toys based on modularity is that they could build upon pre-existing toys, modular or not. Gldenpfennig and others (2018) during a study on interactive toys did this with the aim of “creating a modular system to be used to *augment* existing toys and everyday objects. That is, instead of adding yet another toy to the stock of 1000+, we designed an interactive and open-ended technology to add extra value to existing materials” (p. 6). Whether adapting old toys or creating new ones, modular aspects allow toys to be adapted to the user across different ages as “the four design elements of module shape, module color, construction method, and technology content largely influence the development of children's cognition” (Zheng, 2019, p. 245). Simpler elements that are important for younger children’s development can later be removed or converted to more complex interactions and a higher level of critical thought for older children. For all ages, modularity offers open-ended play. Children from

Güldenpennig's (2018) study "made up their own games", using their imagination to create ways the designers did not previously think of (p. 6).

2.3.3 Other Design Methodologies for Children's Toys

Children's toys should, above all else, foster imagination and create enjoyable experiences. To achieve this result, designers must "clearly support one or more activities that promote the psychosocial development of sensory motor skills and physical ability in the child users" (Coelho, 2013, p. 10). But to start the design process whether abstract or literal, the designer must identify "one or more metaphors that may form the basis of concepts for the creation of toys or recreational objects" (Coelho, 2013, p. 10), for example, drawing on the forms of real world cars to create a more simplified vehicle toy. Once these first steps have been achieved, the designer should then:

4. Evaluate the concepts of toy or object triggered as a result of the previous stage in satisfying a set of requirements generally applicable to toys or objects of play (e.g. low toxicity, safety regarding self inflicted injury) and select those that satisfy the general requirements and that are configured as original proposals, potentially motivating their use by children (by selecting different age groups) and clearly support one or more activities that promote the psychosocial development of sensory motor skills and physical ability in the child users.
5. Develop and set, based on knowledge of the context of child development and the concept selected, a specification in order to guide the design of the toy or playful

object. At this stage market objectives should be considered, including costs, packaging, distribution and consideration may also be given to objectives of another nature.

(Coelho, 2013, p. 10).

The designer may then move toward traditional methods of prototyping and testing “initially with adults and ensuring no hazard is presented” (Coelho., 2013, p. 10).

As mentioned earlier, toys do more than just provide entertainment; they “play an integral role in child development (Brussoni et al., 2012) by transforming abstract ideas into concrete objects, thus helping children connect concepts” (Levesque, 2022). To ensure children can connect concepts, designers must keep in mind the age of the children. Factors that are determined by a child’s age:

mainly involve the appearance factors of toys, such as shape, color, and materials. For example, children of about 3 years old should use high-purity, high-definition, warm-colored colors, and the color...should be clearly defined to improve the child's sensitivity to color. (Zheng et al., 2019, p. 245)

Simpler elements of a toy may not be desired by all ages, but this issue can be addressed through other methods.

2.4 Conclusion

The reality that the design of toys needs to change is evident. In an attempt to fix the issues present in the modern toy market, designers may attempt to utilize any number of ideologies such as modularity, emotional attachment, open-ended play, material sustainability, customizability, or secondary life cycles. A designer may be overwhelmed because while there is extensive research on each topic individually, there are no clear instructions on how to merge these principles in a way that equally promotes environmental sustainability and thought-out, engaging play. These ideas can appear disjointed at first, but through the help of a set of focused guidelines, designers could utilize multiple of these principles to more easily create long-lasting, engaging toys that are environmentally conscious in one way or another.

Chapter 3 - Analysis of Existing Children's Toys

3.1 Categories of Children's Toys

The Toy Association (2023), a group committed to regulations and research on toys, divides toys into 17 categories when announcing “best of” awards, including action figures, collectible, construction toy, creative toy, doll, game, outdoor toy, playset, plush toy, ride-on toy, STEAM toy, and vehicle toy, as well as others based on theme or age range. Pre-school or grown-up toys do not indicate the toy's function or the steps needed to fulfill the design, but rather the target demographic the toy is designed for. Similarly, a collectible toy or a STEAM toy could have the qualities of any other category but was created with a specific play outcome. Defining the category helps determine the broader type of play the toy will be designed to encourage. Dolls, action figures, and vehicles are usually representative and are used to mimic real world activities. Construction toys and creative toys encourage discovery and the exploration of an outcome through play. Ride-on toys, large scale playsets, and outdoor toys encourage physical activity and outside play. Toys can often have multiple uses and as such fall into multiple categories as follows.

3.1.1 Action Figures and Dolls

Action figures are described as “Toys that represent a person or fictional character intended for active, imaginative, and narrative-based play” (The Toy Industry Association, 2023, sect. 2). The line between what constitutes an action figure and a doll is fuzzy at best, with the only distinction made by the Toy Association being that a doll “include[s] baby, toddler, and

fashion dolls” (2023). The difference is usually made culturally rather than purely mechanically, with SYFY Wire (2020) marking the distinction as “...dolls have groomable hair and changeable clothes, while action figures had a smaller scale and specific features that enhanced their play value,” though the article admits “...in the modern era, the line between doll and action figure is getting increasingly blurry. Hot Toys' insanely detailed superheroes are several cuts above any traditional action figure... and yet they seem more suited as dolls...” (para. 2). Both action figures and dolls provide children an outlet for expressing themselves creatively as well as “an opportunity to expand their communication skills” (Buckley, n.d.-b, para. 4). Having a representation of a world, real or fictional gives children an opportunity to create meaning and rationalize concepts they have learned through the “use [of] vocabulary and concepts they have observed in the world around them to explain the action figures’ decisions and movements in the world or within the playset” (Buckley, n.d.-b, para. 4). Playing with figures and dolls with multiple children can be practice for developing social skills, giving children a chance to explain “how the different figures may be thinking or feeling” (Buckley, n.d.-b, para. 6) to others, creating emotional prompts and responses that ultimately become a story.

3.1.2 Construction Toys

Construction toys are made up of a set of pieces, often modular, designed to be built by a child. The primary type of play created by these toys is generally the building process itself. The child either plays by following the instructions provided to learn building techniques or uses their imagination to discover as many end results as they can, either way then going on to play with the toy in its new form. By necessity, construction toy components must be all internally

compatible, able to connect together and allow a child to actually build with them. This can be as simple as flat surfaces that allow stacking, or more complex techniques like interlocking joints. Construction toys “encourage hand-eye coordination and fine motor skills” (Buckley, n.d.-a, para. 3) as well as developing physical awareness and caution. All construction toys provide some level of personalization and most provide a “fun challenge to see what kids can concoct using their imaginations and the building materials in front of them” (Buckley, n.d.-a, para. 4). Because of the similarity of criteria to modular products, designers can rely on those principles when creating a construction toy.

3.1.3 Creative Toys

Creative toys are described by the Toy Industry Association (2023) as “toys that allow kids to build and/or make items that are unique to them” (sect. 5). While both include creation in their play, the difference between a construction toy and a creative toy is that where a construction toy offers a structured system to build and rebuild within, a creative toy allows children a less defined set of tools to express themselves artistically with. These toys encourage creativity through exploring the various tools and techniques provided to create an end result that matches the desired level of personalization. Creative play can be accomplished with simple artistic tools such as “...through providing the child with paints, paper, clay, carpentry materials, crayons, scissors, and glue” (Lambert, 1976, sect. 7) or through more complex playsets that mimic scientific or artistic processes with “toys that help a child raise questions and experiment, help him to investigate and make discoveries on his own” (Lambert, 1976, sect. 7).

3.1.4 Game and Puzzle Toys

Game toys are those that provide a structured rule set and activity for those playing to follow. The Toy Association Industry (2023) categorizes them as “games including board, card, electronic or other physical game formats and puzzles, exclusive of video or app games” (sect. 7). Cetin-Dag (2021) defines a game as a play activity with four basic features:

- Framing: Defines the nature of the behavior during the game. By taking and giving clues, children can understand what the behaviors mean during the game.
- Intrinsically motivated: Children participate and enjoy playing during the game.
- Internal control: It specifies when and what players want to play with. Players decide when they will finish the game through the control mechanism.
- Freedom to suspend reality: There is the freedom to suspend the truth in a game.

(Table 1).

To make a game toy, there must be pieces with designated functions, a ruleset to define those functions, and a framing that allows for a start and end point of play. Game toys may allow children to create their own rules, but the starting point of a given structure is what differentiates game toys from other toys.

3.1.5 Outdoor Toys and Rideables

An outdoor toy is not just a toy that can be played outside, but one that is specifically designed to be. The Toy Industry Association (2023) excludes rideable toys from this category in

favor of designating it separately, but does later clarify that rideable toys are inherently meant to be used outdoors. An outdoor toy can be a toy that is too large to fit indoors, or one that requires ample space for physical activity and to fit the rules of a large-scale game. Rideable toys require room for children to drive around and explore, and sports games like basketball require large equipment and room

3.1.6 Playsets

Playsets are “Toys that are designed to work together to enact some action or event, including characters and role play” (The Toy Industry Association, 2023, sect. 12). Playset toys can be self-contained, encouraging children to play within the provided components, or used as accessories to enhance play and create settings for action figures and dolls. They are largely designed for the latter, often a secondary purchase to fit the provided characters like a spaceship for an astronaut or a house for a doll. Because of this intent, playsets tend to have similar benefits as action figures and dolls. Having a physical setting provides children the opportunity to “combine their real-world knowledge with their imaginations to create stories, scenarios, and adventures with these toys” (Buckley, n.d.-b, para. 3). Playsets can be less literal, especially for children in the sensorimotor stage who are not yet able to make a real world association. These playsets may take the form of matching shaped blocks to a bigger set or stylized pieces of toy food meant to be sorted back into a lunch box. Playsets can also be much larger in structure, not meant to be played with dolls or action figures, but with the children themselves. These also tend to be for younger children in the preoperational stage who are likely to want to replicate adult behaviors like cooking in a toy kitchen or playing “house.”

3.1.7 Plush Toys

Plush toys can be traditional stuffed animals to more complex soft dolls and includes “Toys that are made of fabric and stuffed with soft filling, including toys with interactive or electronic features” (The Toy Industry Association, 2023, sect. 13). Plush toys are often representations of real world objects or creatures, and can help exercise children’s imagination in the same way other representative toys can. Plush toys are considered “transitional objects – inanimate objects that provide comfort, particularly in unfamiliar or distressing situations” (Lai, 2021, para. 1). Plush toys are created with the intention of creating a strong emotional bond with the child, and often treated as a companion more than a toy. Children sleep with stuffed animals for comfort, and will incorporate them into other types of play. Even plush toys that children are not bonded to can help emotionally with frightening tasks like surgery and recovery:

In a study of pediatric patients between the ages of 1 and 7 who had undergone surgery, Ullán et al. (2014) provided the children with a rabbit stuffed animal dressed up as a doctor, along with instructions for parents to use the stuffed animal to play with their child after surgery. They also took measures of the children’s pain based on their behaviors post-surgery, such as facial expressions or crying. Overall, Ullán et al. (2014) found that the children who received the stuffed animal and instructions to play scored lower on the pain measurements (meaning that they exhibited less pain), compared to children who did not. The researchers proposed two explanations for the findings: playing with the stuffed animals could have distracted the children from pain, or playing

with the stuffed animals could have improved the children's mood, which in turn could influence their experience of pain. (Lai, 2021, para. 4)

Plush toys can be more complex, featuring electronic components for sound, lights, and even movement. These features are used to mimic real world animals or fictional characters and creatures for a type of immersive play. The components used to achieve this function often require hard plastic and may interfere with the more therapeutic and transitional nature of ordinary plush toys.

3.1.8 Vehicle Toys

Vehicle toys are made up of “Toy cars, trucks, trains, and other vehicles in all scales, including R/C vehicles but exclusive of ride-ons” (The Toy Industry Association, 2023, sect. 18). The vehicles can be real or fictional, and have varying levels of detail and functionality. Playing with vehicles helps younger children “...begin to grasp fundamental concepts like spatial awareness and cause-and-effect relationships” (Yasmine, 2023, para. 3) as well as develop fine motor skills required to move smaller vehicles and gross motor skills required to move larger carts and wagons. Moving the vehicles across different surfaces can create a sensory experience for children “As they race, jump, and sometimes even crash, toy vehicles create tons of sensory input. This input – the sounds, sights, and tactile aspects of toy cars – helps enhance sensory development in young children” (Yasmine, 2023, para. 6). This experience can be amplified by playsets featuring tracks or roads to guide the cars and potentially propel them.

3.2 Market Assessment of Toys

For the purposes of ranking toy attributes, playsets will be included with the toy category they are meant to be paired with. Each toy category will be compared with itself, as modularity and play function requirements are not equally weighted for each category. Toys may be included in multiple sections if they are designed to be played with in multiple contexts. Outdoor toys will not be considered in this market assessment. Information on material impacts come from Okala Ecological Design Course Guide, and an estimated Life Cycle Assessment value will be assigned based on data from Okala and available information of the toys being reviewed. As a full bill of materials requires disassembly and direct study of each product, the bill of materials will be simplified to measure the listed primary material and weight as provided by retailers. The values assigned will solely reflect the material impact as measured using Step 2 of Okala’s Single Figure Life Cycle Assessment.

STEP 3 > Calculate estimated impacts				STEP 3 > Calculate estimated impacts			
INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS <small>Okala03 millipoints</small>	INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS <small>Okala03 millipoints</small>
PC	0.050 lb	180/lb	9.00	zinc	0.025 lb	81/lb	4.05
				copper	0.043 lb	160/lb	6.88
paper	0.025 lb	27/lb	0.68	cotton	0.044 lb	140/lb	6.18
inj. mold	0.050 lb	11/lb	0.57	paper	0.039 lb	27/lb	1.05
sewing	0.042 kw-hr	20/kw-hr	0.83	machine	0.068 lb	1.2/lb	0.08
truck	0.067 ton-mi	9.7/t.-mi	0.65	sewing	0.026 kw-hr	20/kw-hr	0.52
landfill PC	0.050 lb	1.6/lb	0.08	truck	0.103 ton-mi.	9.7/t. -mi	0.99
landfill paper	0.025 lb	5.3/lb	0.13	landfill zinc	0.025 lb	0.25/lb (est.)	0.006
				landfill copper	0.043 lb	0.25/lb (est.)	0.01
				landfill paper	0.039 lb	5.3/lb	0.21
TOTAL IMPACTS/LIFE BUTTONS: 11.94				TOTAL IMPACTS/LIFE ZIPPER: 19.976			

Figure 5: Step 3 > Calculate Estimated Impacts (White et. al., 2004)

Using the single figure LCA guidelines, each functional unit can be measured as a “play scenario”, in which a child is able to play with the toy, while the total life is measured by total

play scenarios a toy provides. The final equation will be compared per each toy category by using the Y axis to reflect lifetime use against the impact values on the X axis.

3.2.1 Action Figures and Dolls

The Barbie Dream Camper is a dual RV toy and playset that has folding panels to convert between the two modes. Children are encouraged to reenact real world camping activities, from driving to the site to sleeping under the stars and cooking out. While in RV mode, the Camper can fit four dolls as it rolls around. Panels unfold to create a playset environment that, with accessories, looks more like a living environment. Additional panels can be unfolded to reveal new play activities with a bathroom and shower on the opposite side of the main play area and an over 30-inch high slide that connects to a small fillable pool. The accessories meant for the main play area can be conveniently placed inside the vehicle while in RV mode for storage purposes and rearranged to allow a child to decorate the space for dolls. Having multiple functions and an advertised seven play areas allows a seemingly compact toy to be used in a variety of ways, provided that a child also buys Barbie brand or comparable dolls as they are not included in the set itself. It is assumed that the Barbie Dream Camper is made from ABS plastic.



Figure 6: Barbie Dream Camper (Amazon, n.d.-a)

Barbie- Dream Camper

Materials		
ABS	7.72 lbs	
Estimated Impact		
47x	7.72 lbs	362.84

Figure 7: Barbie Dream Camper LCA



Figure 8: Barbie Fashionista #218 (Amazon, n.d.-b)

Barbie Doll- Fashionista #218

Materials		
ABS	0.38125 lbs	
Estimated Impact		
47x	0.38125 lbs	17.91875

Figure 9: Barbie Fashionista #218 LCA

Bratz is a line of fashion dolls created by MGA Entertainment in 2001. The dolls have exaggerated features and cartoonish proportions, all coming with a full set of clothes and accessories. The line has very few larger sets, mostly consisting of furniture pieces for the dolls

to sit in. The main play from Bratz dolls comes from the customization of the outfits they wear, with each piece of clothing being an individual accessory that can be added and removed as desired. The pieces of clothes themselves are not customizable and come as static components. The dolls themselves are not changeable and represent original characters.



Figure 10: Always Bratz Cloe Fashion Doll (Amazon, n.d.-c)

Bratz- Always Bratz Cloe

Materials		
ABS	0.68125 lbs	
Estimated Impact		
47x	0.68125 lbs	32.01875

Figure 11: Always Bratz Cloe LCA

Marvel Legends is a Hasbro line of 6” action-figures meant to be highly detailed, highly articulate, and collectible. The line was originally launched in 2002 by ToyBiz with each figure representing a character from Marvel comics, movies, and games. Each figure comes with interchangeable pieces, whether it be alternate heads, hands, or weapons for customizable

posing. A gimmick of the Legends line is the Build-A-Figure, a disassembled figure with each piece in one box of another character in a set wave. This is meant to encourage the purchasing and collecting of figures that the user may not want in the goal of collecting and assembling the full buildable figure. This leaves the component of the Build-A-Figure useless if all characters in a wave are not purchased, as the core figures themselves have inconsistent pegs and ports and are not meant to be reconfigured beyond the additional character specific pieces.



Figure 12: Marvel Legends Series Cyclops (Amazon, n.d.-f)

Marvel Legends- Cyclops (X-Factor)

Materials		
ABS	0.36875 lbs	
Estimated Impact		
47x	0.36875 lbs	17.33125

Figure 13: Marvel Legends Cyclops LCA

Transformers is an action-figure toy line named after its primary gimmick, each toy being a robot that is able to transform into one of a variety of vehicles, objects, or creatures. Originally

a Takara Tomy line named Diaclone, the toys were rebranded and sold by Hasbro in the United States in 1984. The toys vary widely in complexity, being as simple as one button mechanics to change forms or highly detailed and articulated figures requiring puzzle-like maneuvers to fully transform. The primary line of Transformers currently is titled “Legacy.” Legacy leans toward a more complex style of toy, usually having detailed articulation as a figure and working moveable components in its secondary, and sometimes tertiary, form such as rolling wheels or posable limbs. Transformers Legacy toys have a very limited element of modularity, with each weapon and weapon port, including hands, having a 5mm width. These ports are currently universal between Transformers of the same scale, meaning Legacy weapons and tools can be used with the Studio Series line, a collector oriented line that recreates Transformers from a variety of media. While otherwise not modular, a Transformer is marketed as a “2-in-1” toy due to the possibility of the robot mode as an action-figure and the ability to convert into a vehicle with working wheels, now playable as a toy car. As long as the transformation has enough involvement from the user, a Transformer could be considered a 3-in-1 toy as the conversion between two modes can become a kind of puzzle or fidget toy.



Figure 14: Transformers Legacy Evolution: Beachcomber (eBay, n.d.-b)

Transformers- Beachcomber

Materials		
ABS	0.24 lbs	
Estimated Impact		
47x	0.24 lbs	11.28

Figure 15: Transformers Legacy: Beachcomber LCA

While not modular or designed with multiple functions in mind, a Barbie doll’s playability is enhanced by the Dream Camper’s ability to create multiple play functions. Both Transformers and Marvel Legends figures have limited modularity, with the ability to be customized with standardized accessories, but Transformers playability is further enhanced by its secondary functions.

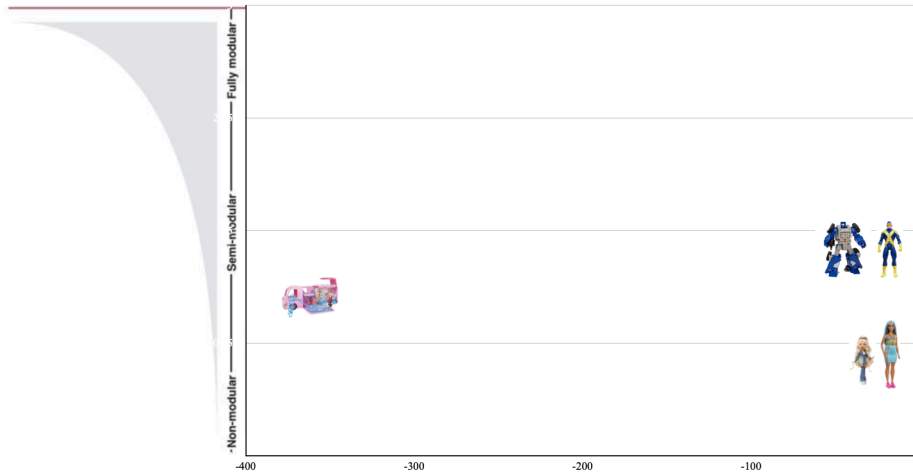


Figure 16: Action Figures and Dolls Modularity Rankings

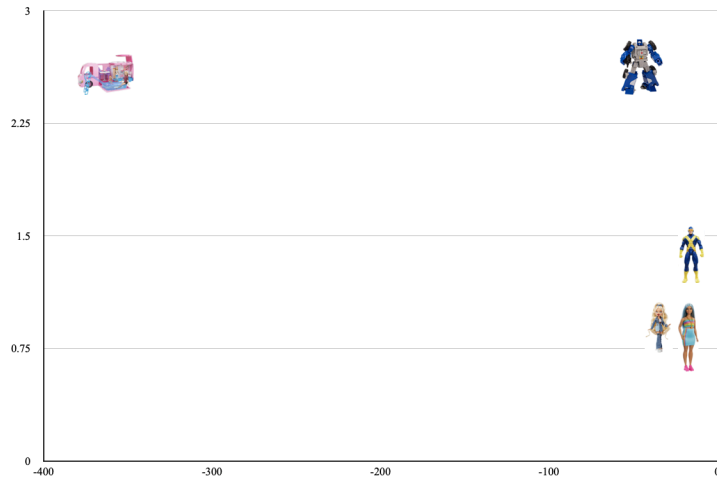


Figure 17: Action Figures and Dolls Play Function Rankings

3.2.2 Collectibles

Zuru’s Mini Brands is a collectible line of 1:12 scale objects representing real purchasable branded goods, ranging from fast food, furniture, technology, toys, and others. Mini-Brands come in a blind-box format, having random objects from an advertised line of goods. The objects alone have no inherent function beyond collecting, and must be combined with other toys to create play, such as using the objects as board game pieces or adding them to a doll’s house to replicate having real products. They lack customization, individual play potential, and opportunity for secondary use. Because they are primarily designed to be a small collectible, their individual impact is small, but scales rapidly as customers purchase multiple.



Figure 18: ZURU Mini Brands Sneakers Series 1 (Amazon, n.d.-g)

ZURU Mini Brands- Sneakers 1 pack

Materials		
ABS	0.15625 lbs	
Estimated Impact		
47x	0.15625 lbs	7.34375

Figure 19: ZURU Mini Brands- Sneakers 1 Pack LCA

Smashers by Zuru is named after the main gimmick its packaging employs, smashing it apart to reveal the toys inside, similar to a piñata. Smashers come in several themes including “Horror House” and “Monster Trucks” but are mostly modeled after the starting theme of “Dino Eggs.” The main play of Smashers is from its collectible mystery box nature, each product advertising anywhere between 15 to over 25 surprises inside the main casing. The components inside range from simply being collectibles, like stickers and “treasure” pieces, to more complex representative dinosaur or fantasy creature action figures. The majority of the pieces included in each box are very simplistic with little to no moving components or interchangeability. Each Smasher also includes either foam sand or slime, usually used to hide one of the other toys.

While the main excitement of the toy is the surprise and excitement of “smashing” everything and discovering what toys the child now owns, each Zuru Smashers allow for the reuse of the main packaging. After being opened, the larger container as well as the smaller individual containers can all be rebuilt and snapped together. While not necessarily for play, this still allows the packaging to be reused for decoration or storage for the provided pieces or something else.



Figure 20: Smashers Dino Ice Age Mini Surprise- T-Rex (Amazon, n.d.-i)

ZURU Smashers- Dino Ice Age

Materials		
ABS	1.47 lbs	
Estimated Impact		
47x	1.47 lbs	69.09

Figure 21: ZURU Smashers Dino Ice Age LCA

While both ZURU collectible products have low modularity and play functionality, the Smashers series is much higher on a function scale as it has a clear play intent with the different toys included and reusability of the egg casing. The Mini Brand toy however, has a uniquely low ranking as it has no discernible play function without the purchasing of a separate toy.

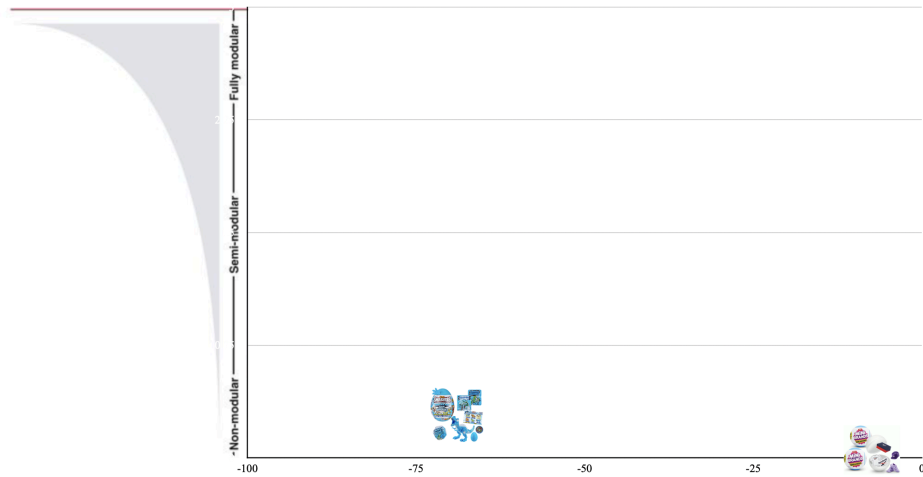


Figure 22: Collectibles Modularity Rankings

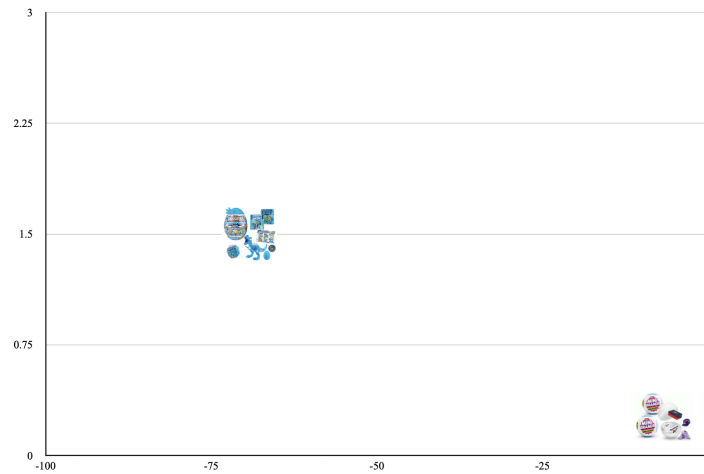


Figure 23: Collectibles Play Function Rankings

3.2.3 Construction Toys

Erector is a construction and STEAM toy line by Meccano made up of metal plates, bolts, and other components. Originally launched in 1913, Erector sets were inspired by steel construction girders and meant to encourage children to explore engineering. Erector products

usually advertise multiple end results in one kit, with instructions that teach techniques to build outside the given examples. Many kits include motorized components that allow for wheels to turn and, in more complicated sets, pulley systems to spin. The product is advertised as including real tools that allow children 10 and up to learn while building. The ironic downside of Erector being so realistic in its construction is how sturdy the final products are. Tight fastenings and sturdy connections mean once a child has finished building a motorized crane it will be able to actually lift objects and move around without falling apart. However, this sturdiness also prevents easy disassembly of the model, requiring children to unscrew and unbolt every fastening in a somewhat time consuming manner. Its durable steel components allow for the type of play intended, but may potentially hinder its reuse.



Figure 24: Meccano Erector 5-in-1 Model Motorcycle (Meccano, n.d.)

Erector- 5 in 1 Motorcycles

Materials		
Steel	0.75 lbs	
Estimated Impact		
29x	0.75 lbs	21.75

Figure 25: Erector 5 in 1 Motorcycles LCA

Hex Bugs is a brand of robotic bug-like toys created by SpinMaster that uses vibrations to propel itself along rubber legs. They come in a variety of shapes and sizes, but the most popular is the HexBug Nano. Playing with the toy by itself can be very idle, as the main function is its movement and it will propel itself forward along any surface the legs can rest upon. However, the hexagonal based playsets as part of the Nano line can be built and recombined into a multitude of courses the HexBugs can move through. Posts can be placed in the main pens to guide the “bugs,” ramps can take them to new layers, and lane shaped connectors allow them to move into new areas. The V2 Nano has rubber feet along its back, allowing it to move through the tunnels at any angle, “defying gravity” as the packaging says. Alone, the HexBug nano can only be considered an idle robotic toy, but with any form of play set it becomes a construction toy where the play becomes creating new pathways to watch the Nanos move through.



Figure 26: HEXBUG Flash Nano (HEXBUG, n.d.)

HEXBUG- Flash Nano Single

Materials		
PP	0.088125 lbs	
Estimated Impact		
58x	0.088125 lbs	5.11125

Figure 27: HEXBUG Nano LCA



Figure 28: HexBots Nanotopia (Walmart, n.d.)

HEXBUG- Nanotopia

Materials		
HDPE	3.80 lbs	
Estimated Impact		
25x	3.80 lbs	95.00

Figure 29: HEXBUG Nanotopia LCA

K’NEX is a modular construction toy composed of plastic rods, gears, and snapping connector pieces created in 1992 by Joel Glickman and now owned by “Basic Fun!”. K’NEX has an estimated 15 standard parts, with many specialized components like motors and ball tracks. This smaller number of parts may limit the range of possible builds, but the structural rods and gear like connections allow it to specialize in creating vehicles and large architectural builds. A popular set theme of K’NEX is amusement park rides, as the larger rods and special pieces allow for the building of mechanical contraptions like ferris wheels or marble roller coasters. Wheels and flexible pieces allow the very geometric nature of the toy to be adjusted to more realistic, vehicle like forms.



Figure 30: K’NEX- 35 Model Ultimate Kit (Basic Fun, n.d.)

K'NEX- Adventure Wheels

Materials		
Nylon	0.6625 lbs	
Estimated Impact		
99x	0.6625 lbs	65.5875

Figure 31: K'NEX LCA

LEGO is a modular building block construction toy created as we know it today by the LEGO Group in 1958. The LEGO Group created several building blocks and patented their “clutch power system” that utilizes “studs and tubes” in 1958. The first “system within a system” was introduced in 1978 with the LEGOLAND town. LEGO has gone on to create several themes with both original properties and licensed materials, producing 42 different set themes in 2022. LEGO on its own is a totally modular construction toy as their system allows nearly any piece to connect to another using the standardized studs and tube sizing, even with specialized “technic” frame pieces or theme specific pieces. Children can build whatever they choose with the blocks, and parents can buy bulk bins of assorted blocks for this purpose. LEGO’s themed sets still act as a construction toy, but are often intended primarily to be playsets. A Star Wars, City, or Friends set functions almost identically to a doll or action figure playset, but with the added experience of a child building it themselves. However, because LEGO is completely modular, the playsets can be customized and even entirely rebuilt and combined with any other set. LEGO has created several art kits, where buyers are encouraged to personalize objects and create art pieces within the given set or outside. LEGO also has many vehicle sets, either meant to be played within their City theme, within another media theme, or built and rebuilt within a Creator set. The simplicity

and standardized approach of LEGO bricks allow them to be built in ways to mimic nearly any other indoor toy function, giving a child the guidelines to understand how to build but allowing them to determine the true product boundaries. The range of LEGO and its scaling complexity allows it to be a toy that evolves with its user, starting out as a simple built toy that can be reused into a customizable model kit.



Figure 32: Creator 3-in-1 Aircraft: Race Plane (LEGO, n.d.)

LEGO- Creator 3 in 1 Plane

Materials		
ABS	0.6625 lbs	
Estimated Impact		
47x	0.6625 lbs	31.1375

Figure 33: LEGO Creator 3-in-1 Plane LCA

Magna-Tiles is a brand of construction toys made up of plastic geometric pieces with magnets along each side. Beyond specific themed pieces, each tile can connect to every other tile using the interior magnets despite differing shapes. The multi-colored tiles can be connected along edges or faces, meaning the only limits to building are the geometric constraints of the tile

shapes, gravity, and imagination. However, Magna-Tiles have little secondary play potential once built due to the loose connection formed by the magnets leading to fragile structures. Specific set pieces like plastic tile based animals can be used as tokens in a created play environment, but are not able to combine with standard pieces beyond holding them upright.



Figure 34: Magna-Tiles 32 Piece Set (Kaplan Early Learning Company, n.d.)

Magna Tiles

Materials		
ABS	0.67 lbs	
Estimated Impact		
47x	0.67 lbs	31.49

Figure 35: Magna Tiles 32 Piece LCA

As all construction toys compared have inherent additional play functions, they were compared solely on their modularity ranking as a higher score gives a construction toy a higher potential for new functions. Toys like K’NEX and LEGO have potential for more additional play functions because of their completely standardized connection points when compared to a semi standard system like Erector or Magna Tiles. While not primarily a construction toy, the Hex

Bugs Nano play function is increased significantly with the ability to customize the modular playset.

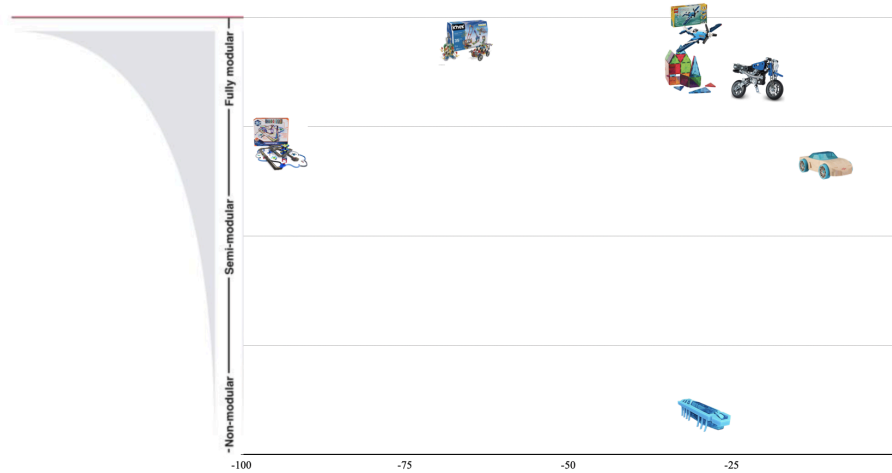


Figure 36: Construction Modularity Rankings

3.2.4 Creative Toys

Scribble Scrubbies by Crayola are white, velvet-textured, molded plastic animals meant to be “scribbled” on, customized with Crayola brand markers, paint, and dyes and later “scrubbed” through an included plastic bathtub or brush. Most of the figures have opposable heads, with some having posable limbs. Users are meant to decorate and personalize the animal figures however they want, allowing them to express themselves creatively and grow attached to the toy as a sort of work of art. Whenever they want the toys to change, they can do so through a cleaning process that is integrated as part of the play with the themed sets. While having limited physical configurations, the toys can have potentially unlimited decorative exteriors, so long as the toys are drawn with compatible Crayola products. Not all of the figures come in full sets, and the ones that do will include some type of pool, shower, or bath to clean them in. This can

become redundant since every pet is compatible with any type of water and cleaning tool, so parents who purchase multiple playsets will end up with several cleaning tools that may have slightly different play features, but ultimately all serve the same play function with no way to change. This problem could be avoided by having designated starter sets where the only exclusive piece is the cleaning component. This way, if a child desires a specific figure or color of Crayola marker, they can be purchased separately as needed while avoiding redundancies.



Figure 37: Scribble Scrubbie Arctic Igloo Playset (Crayola, n.d.)

Crayola Scribble Scrubbies- Igloo

Materials		
PVC	0.70625 lbs	
Estimated Impact		
41x	0.70625 lbs	28.95625

Figure 38: Crayola Scribble Scrubbies Arctic Igloo Playset LCA

Play-Doh is a clay like creative modeling toy created by Kutol in 1955 and currently owned by Hasbro. Play-Doh itself is incredibly simple, being a dough-like compound created

with flour used similarly to clay for arts and crafts purposes. The dough is theoretically always reusable as even if it dries out water can be added to return it to a similar state to its original. Play-Doh is frequently sold with playsets which provide molds and mechanics to shape the dough into a specific object or shape with an involved process. The same white dough can be pressed through a food playset into an ice-cream cone or through a dentistry set as a new tooth for the toy patient. The toy is completely malleable, becoming whatever a child decides it is through a playset or through imagination. The restriction of Play-Doh is that its simplistic material makeup and smaller playsets limit the age it can be played with, as there are few ways to add complexity for older children to engage with.



Figure 39: Play-Doh Fun Factory (Amazon, n.d.-h)

Play-Doh- Fun Factory

Materials		
HDPE	0.50 lbs	
Estimated Impact		
25x	0.50 lbs	12.50

Figure 40: Play-Doh Fun Factory LCA

Creative toys often have little modularity as having a standardized shape may limit the toy's ability for customization. What is more important is how flexible and how personalized a creative toy can be. The Doodle Bear is customizable and reusable, but is slightly limited in its play functions due to the standard constraints of a plush toy, compared to the Crayola Scribble Scrubbies which can be combined with playsets. Play-Doh is completely malleable, and is only slightly limited by its reliance on molds to create clear play scenarios.

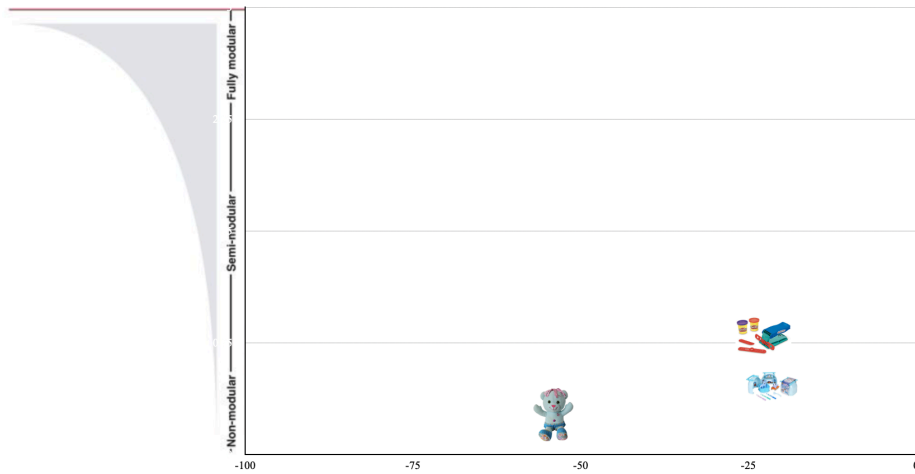


Figure 41: Creative Toy Modularity Rankings

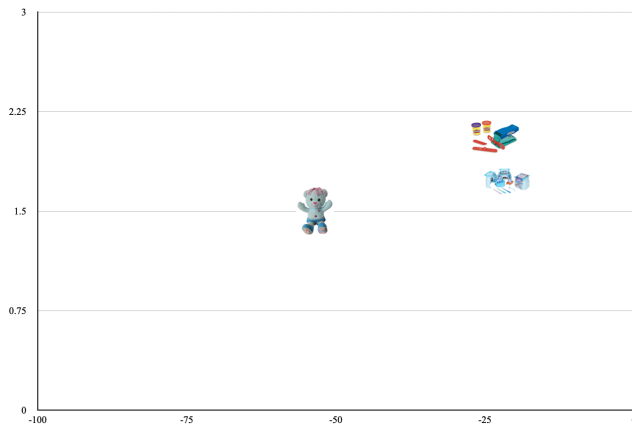


Figure 42: Creative Toy Play Functions Rankings

3.2.5 Game and Puzzle Toys

Beyblade X is the most recent line of Takara's and Hasbro's Beyblade toys. Beyblade toys take inspiration from "Beigoma," a traditional Japanese top. Much like the original toy Beyblade "battles" consist of players spinning their tops via rip cord, competing to see whose will spin longer or knock the others out of the "arena." The toys were first created in 1999 and consisted entirely of plastic until 2008 when Beyblade switched to a core metal ring with the "Hybrid Wheel System" often referred to as Beyblade Metal. Beyblades are categorized under one of four battle types: attack, defense, stamina, and balance. The type of the top is determined by how the components affect weight, speed, balance, spin pattern, impact and a variety of other factors. This case study will directly compare the Hybrid Wheel System Beyblades to the X line.

The Beyblade Hybrid Wheel System consists of five components for each top: a "face bolt," an "Energy Ring," a "Fusion Wheel," a "Spin Track," and a "Performance Tip." The majority of the top is held together with the Face Bolt, screwing into the Spin Track to hold together the Energy Ring and Fusion Wheel, with the Performance Tip locking onto the bottom of the Spin Track. These components can be freely interchanged with other Hybrid Wheel System Beyblades and determine the name of a Beyblade being sold in retail. For example, "Rock Aries ED145B" is a top with the Face Bolt and Energy Ring "Aries," the Spin Track "Eternal Defense 145," and the Performance Tip "Ball;" while Storm Aquario is a top with the Face Bolt and Energy Ring "Aquario," the Fusion Wheel "Storm," Spin Track "100," and Performance Tip "Hole Flat/Spike." Because each piece is modular with other Beyblades of the same line, changing components from the two examples above can create "new" Beyblades such

as “Storm Aries 100B” or “Rock Aquario ED145HFS.” Assuming the Face Bolt and Energy Ring are used together, up to sixteen different tops can be built using the ten total components from just these two Beyblades, twenty-five if the Face Bolt and Energy Ring are used independently of each other. Each top is dropped from a launcher that has two teeth to hold the Beyblade and a rip-cord. The teeth of the launcher fit into slots created by the Energy Ring and Fusion Wheel.



Figure 43: Storm Pegasus 105RF (Coleka, n.d.)

The Beyblade X system consists of three components for each top: a “Blade,” a “Ratchet,” and a “Bit.” Released fifteen years after the Beyblade Hybrid Wheel System, Beyblade X simplifies the construction of the tops with the Ratchet twisting onto the bottom of the Blade, and the Bit slotting into the two pieces at the bottom. This was done to replicate a Beyblade “Burst” feature, where if the top sustains enough hits, it will explode into pieces, rewarding points to the opponent. Another distinct difference is the gear shapes just above the tip of the Bit, meant to hook onto the new Rail gimmick in “arenas.” “Helm Knight 3-80N” is a top with the Blade “Helm Knight,” the Ratchet “3-80” (which has 3 points and is 80mm tall), and a Needle Bit; while “Keel Shark 4-60LF” is a top with the Blade “Keel Shark,” the Ratchet “4-60”

(which has 4 points and is 60mm tall), and a Low Flat Bit. The tops are still modular, with each piece being interchangeable with components from other Beyblades in the X line. Now with only three pieces, two Beyblades from the X line can be disassembled and turned into nine different tops such as “Helm Knight 3-60N” or “Keel Shark 3-80LF.” This reduction in combinations is due to the Blade component consisting of three parts that would have been the Face Bolt, Energy Ring, and Fusion Wheel in the Hybrid Wheel System. While less customizable, the simple naming convention of pieces allows users to customize the tops.



Figure 44: Sword Dran 3-60F (Mall of Toys, n.d.)

Beyblade X- Sword Dran

Materials		
Zinc	0.24 lbs	
Estimated Impact		
81x	0.24 lbs	19.44

Figure 45: Beyblade X Sword Dran LCA

Comparing the two products they could be used together, but are clearly not meant to be. This point is reinforced by the instructions of a Beyblade X product which reads: “Only

compatible with the Beyblade X system.” The two Beyblade lines have distinct component systems, so despite both being completely modular, there is no overlap between the two systems. Additionally, even though both types of tops are built extremely similarly with a plastic tip, ring, and top sandwiching a metal disc, they cannot be used together due to a large height difference in the toys. Upon testing a Hybrid Fusion Wheel Beyblade against a Beyblade X top, the Fusion top was too low to connect with the metal disc of the X, repeatedly striking the plastic Ratchet. Beyblades are made to be very durable with the metal discs, Wheels, or Blades made from a zinc alloy and the rest of the top cast from a PMMA plastic, but the plastic is likely not durable enough for repeated strikes against the much tougher alloy. Additionally, the launchers of the Fusion line have two hooks to hold the top and protruding teeth on the rip-cord while the X launcher has three hooks and recessed teeth on the rip-cord. The customization of Beyblade X tops are more technically straightforward in how to change the performance of each toy and do allow for an engaging gimmick of bursting, but lose a sense of character and emotional durability from no longer allowing users to create their own “characters” by mixing and matching the colorful plastic rings and character based faces. Finally, the hollow center of Fusion line Beyblades could have been kept in mind with the production of the X line’s Bits, with the new Bits being approximately 7.5mm and the gap in a Fusion top’s Spin Track being approximately 8.5mm. Upon testing, a Beyblade X Bit can be roughly fit into a Beyblade Fusion’s Spin Track and can make the Fusion top a similar height to the X, but with nothing to secure it, can still not properly be used with the newer toy.



Figure 46: Beyblade X Xtreme Battle Set (Hasbro, n.d.)

Beyblade X- Xtreme Battle Set

Materials		
HDPE	2.49 lbs	
Beyblade x 2	- 0.24 lbs	
Estimated Impact		
25x	2.01 lbs	50.25

Figure 47: Beyblade X Xtreme Battle Set LCA

Despite being a uniquely durable toy, designed specifically to battle one another and take repeated hits and interchange parts from one another to create new, unique, and personal versions of the toy, Beyblade falls just short of being a timeless product. The different toy lines could have been used together, allowing the older Fusion line to evolve with the new gimmicks like the “Xtreme Rail” the new shaped gear Bits are meant to interact with. This is proven by many fans modeling and 3D printing Bit attachments for the older Hybrid Fusion Wheel tops, allowing the old tops to spin along the rail systems in new stadiums. Takara Tomy and Hasbro could have put more forethought into ways for different lines to interchange, or alternatively sold upgrade parts

allowing both companies to make money off of a new gimmick and line but preserve the use of older toys going forward.

Connect 4 by Hasbro is a simple game toy composed of red and yellow discs and a blue frame that is seven tiles wide and six tiles tall. Created in 1974, the base game has not changed, still requiring a player to connect four of their color pieces in a consecutive diagonal, horizontal, or vertical line. The simplicity of the toy allows it to be rethemed to popular fictional characters or recreated with added components to enhance its complexity. Because the base frame is easy to use, pieces can be removed one at a time or all at once to add rules to the original game. Popular rule variations include “popout”, “pop 10”, “connect 5”, and “power-up”. Children may also create their own rules within the confines of the given components. Connect 4 may seem overly simplistic, but its little material use and its potential for reuse and replay make it an over 50 year old popular game toy.



Figure 48: Connect 4 Classic (Kroger, n.d.)

Connect 4

Materials		
ABS	0.93125 lbs	
Estimated Impact		
47x	0.93125 lbs	43.77

Figure 49: Connect 4 Classic LCA

While not modular itself, Connect 4’s standardized pieces have allowed users to create their own game modes, creating personal gamemodes. On the other hand, the Beyblade X Xtreme Arena has no opportunity for personalization or modular itself, but its primary play function may be enhanced by the modular customization found within the Beyblade X tops.

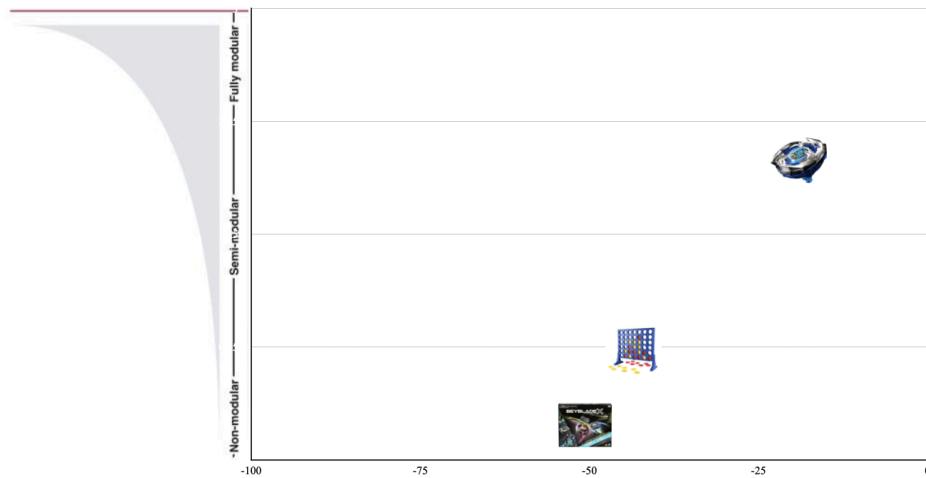


Figure 50: Game and Puzzle Toy Modularity Rankings

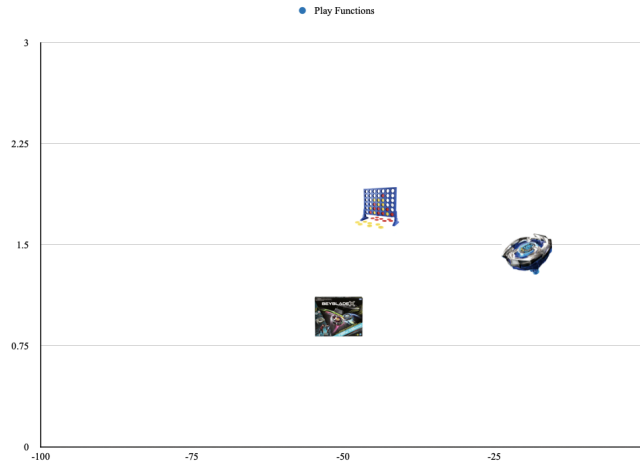


Figure 51: Game and Puzzle Toy Play Function Rankings

3.2.6 Plush Toys

The Doodle Bear was a plush toy created in 1995 by Tyco with the intent of being a stuffed bear that could be customized with an included set of markers. The rights to the toy, and sometimes the company who produced the toy, were routinely sold, changing hands between Tyco, Play Along Toys, Mattel, Fisher Price, and most recently in 2019, Takara Tomy. The Doodle Bear has relaunched several times, each time being sold with a set of markers and a fabric that allows the plush to be continuously washed and redecorated. This feature allows the plush toy to be personalized and used as a creative canvas, encouraging an emotional attachment each time a child is able to create the bear in their own image. Instead of asking for a new bear, children can wash the toy and draw again to fit their preferences. While not currently on the market, several similar products based on the Doodle Bear are, including “Scribble Me: Friends” and “Doodle Dolls.”



Figure 52: Doodle Bear 1994 (eBay, n.d.-a)

Doodle Bear

Materials		
PP Fiber	0.93125 lbs	
Estimated Impact		
58x	0.93125 lbs	54.0125

Figure 53: Doodle Bear LCA

A collectible plush toy by MGA Entertainment, Fluffie Stuffiez is packaged as a hidden animal or object that is revealed during the unboxing process. The marketing behind this toy sells it as having three modes of play with the plush. Since the toy is a collectible, the “fluff” hides the true pattern of the plush inside the packaging, allowing the child to pull it off to reveal the actual plush. This activity is marketed as two separate types of play, the first being pulling the fluff off the plush, and the second being the surprise of the reveal. These two types of play, however, are inseparable. The third advertised mode of play is “stuffing” the plastic shell packaging with the fluff to create a second toy. This toy has a similar shape to the actual plush, but is protected by a

tougher plastic shell that is hindered as an individual toy by the outer frame required for shipping and the large zipper. It may be possible to play with this casing as a second toy, but because of its material restrictions could never serve the same functions as a soft, stuffed toy. Fluffie Stuffiez has the potential to be a toy with multiple types of play, but falls short. Trying to reuse the packaging is a noble goal, but material may have been potentially saved by having the fluff covering the plush be used to stuff the toy itself rather than the plastic shell, which may have reduced the size of the overall package.



Figure 54: Fluffie Stuffiez Pegasus (Amazon, n.d.-d)

Fluffie Stuffiez

Materials		
PP Fiber	0.40 lbs	
Estimated Impact		
58x	0.40 lbs	23.2

Figure 55: Fluffie Stuffiez- Pegasus LCA

Squishmallows is an egg-like shaped collectible plush toy line created by Kelly Toys Holdings in 2017. The plushies are made to look like creatures or characters, all using the same base shape and style of a rounded body with soft simplistic features, occasionally with limbs. Squishmallows have been described as “ultrasoft”, and because of their marketing as a collectible toy, have been purchased for children and adults alike. As a collectible toy, their simplistic form and design language allow them to be visually grouped as part of the same line. Whether the toy is a forest animal or Disney character, it is still recognized as a Squishmallow. They can provide similar benefits to classic stuffed animals, being used as an emotional object that is slept with, cared for, and brought along by a child.



Figure 56: Squishmallows Original 12-Inch Miss Vi Blue Axolotl (Amazon, n.d.-j)

Squishmallow		
Materials		
PP Fiber	0.50 lbs	
Estimated Impact		
58x	0.50 lbs	24.00

Figure 57: Miss Vi the Blue Axolotl LCA

It is difficult to impossible to make a plush toy modular, so the plush toys were combined on a play function basis. Squishmallows are very simple, and meant to be a collectible of sorts, so have a baseline ranking of play functionality. Fluffie Stuffiez scores only slightly higher due to the attempt to create a play experience out of the “mystery box” process, while the Doodle Bear ranks the highest because of its secondary function as a creative, customizable toy.

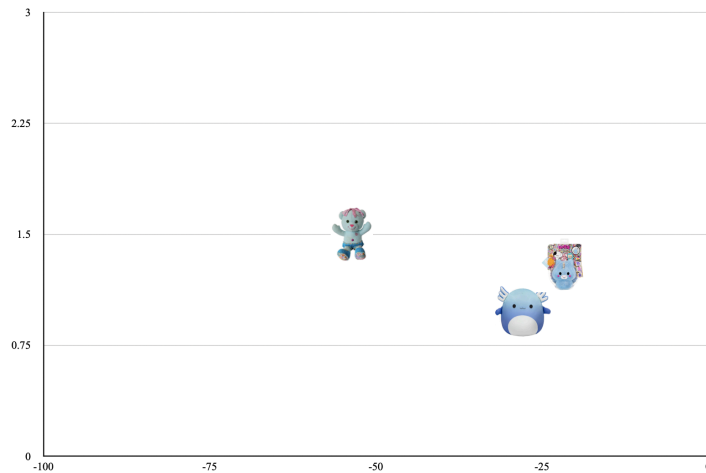


Figure 58: Plush Toy Play Functions Rankings

3.2.7 Vehicle Toys

Automoblox is a wooden car that doubles as a construction toy with its component system. Each car is made up of a wooden front, middle, and rear along with a polycarbonate windshield and four wheels, each with rubber tires. Originally released in 2003, the construction system of the cars has changed several times, and is currently sold as a “Mini” scaled line made of European beech wood. Due to the frequent changing of systems, the Mini line is not backward compatible with other Automoblox toys. Each wheel can connect to one of four ports, two on the front and two on the back. The main wooden blocks are oriented forward and rounded

off at the ends of the cars, so the rear may be attached to the front, but not the inverse. This limits the construction aspect of the toy as it is not completely modular, but preserves the primary intent of the toy as a car, ensuring that any configuration using the minimum parts functions as a car. Automoblox Mini are made at 1:36th scale and are most commonly released in two-packs, allowing users to mix-and-match the pieces out of the box.



Figure 59: Mini C11 Nebulous Aqua Blue (Kidding Around, n.d.)

Automoblox

Materials		
Oak	0.97 lbs	
Estimated Impact		
11x	0.97 lbs	10.67

Figure 60: Mini C11 Nebulous Aqua Blue LCA

Hot Wheels by Mattel is a collectible toy car line modeled at 1:64th scale and designed to be raced or launched through different play-sets or tracks. The cars themselves are unchanging, made to represent real life or fictional vehicles ranging from a Porsche 911 to the Mystery Machine from Scooby Doo. They cannot be easily modified or added to, and serve as simple

collectible toys that can be pushed across most surfaces. However, these collectible cars can be placed into a branded track system. The track system is how Hot Wheels shifts from a simple pocket sized car to a dynamic play-set. The foundation of the track system is simple: long orange tracks connect to one another using blue tabs. However, these tracks can connect to more complex features like battery-powered launchers, loops, or ramps to create more dynamic structures. Most play-sets feature at least one start and end point that can be tabbed into the tracks and made into a larger continuation. While the base of the play-sets are unchanging, many of the sets are partially made from a more flexible track type that allow for the pieces to be taken apart and reassembled into new shapes. While the Hot-Wheel themselves can not be re-configured, the tracks can, which raises the toy's potential to change; however the high expense of the sets and tracks when compared to the cars themselves hinder this potential.



Figure 61: Hot Wheels Lotus Emira (Amazon, n.d.-e)

HotWheels

Materials		
Zinc	0.11 lbs	
Estimated Impact		
81x	0.11 lbs	8.91

Figure 62: Hot Wheels Lotus Emira LCA



Figure 63: Hot Wheels Track Builder Deluxe Stunt Box (Mattel, n.d.)

HotWheels Track Builder

Materials		
LDPE	2.49 lbs	
Estimated Impact		
36x	2.49 lbs	89.64

Figure 64: Hot Wheels Track Builder LCA

Vehicle toys can be easily enhanced through both modularity and secondary play functions. Hot Wheel cars' simplicity can be easily built upon as their size allows them to be used across a variety of surfaces using standardized Hot Wheels tracks. Automoblox may remain a vehicle in all forms, but can be customized and changed to create new play scenarios. Because

Transformers can fully convert, their play scenarios as a vehicle may not increase, but their play functions do as the figure is changed.

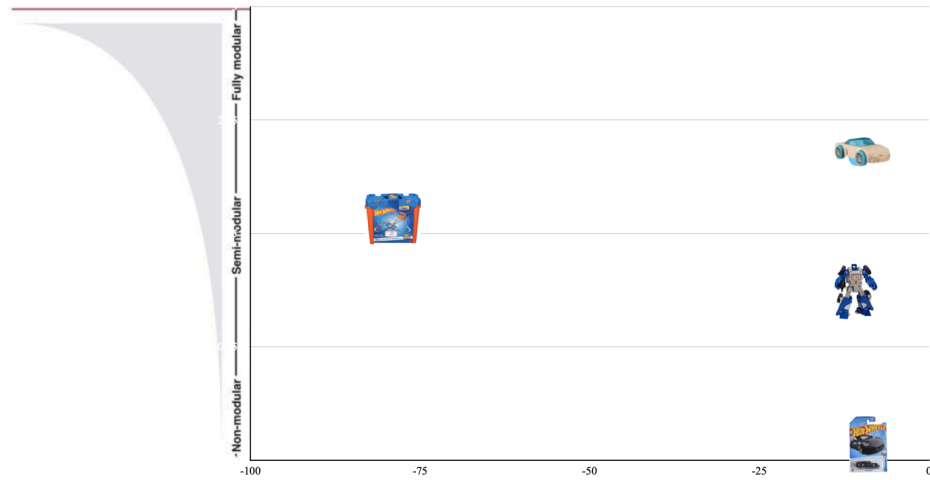


Figure 65: Vehicles Modularity Rankings

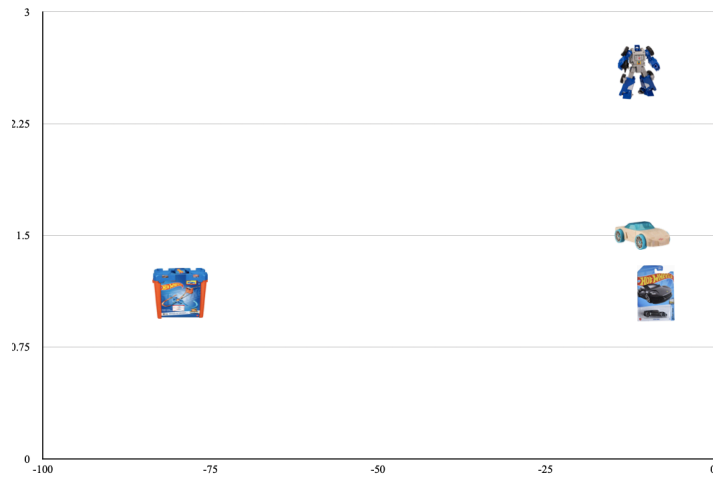


Figure 66: Vehicles Play Function Rankings

3.3 Findings

Through the addition of modularity and play functions, a toy's impact per functional unit will decrease as the total lifespan increases. Increasing the length of play scenarios as well as creating additional play scenarios helps this goal. While a toy is ideally designed to have a low impact production and lifespan, the highest material impact toys such as the Barbie Dream Camper can have their total life span increased. Based on the Okala guide, the final step in the Life Cycle Assessment is to divide the impact by the total functional unit time, where if it is assumed that play functions increase the lifetime use of a functional unit, impact may be significantly reduced.

Chapter 4 - Synthesizing an Approach for Toy Design

4.1 When to Utilize the Approach

The primary focus of this approach is to develop toys with prolonged product life-spans through modularity and multifunctionality. This can not be achieved through a “one size fits all” solution, and will vary based on chosen toy category, chosen toy complexity, and desired play outcomes. While the target user’s age is important, it is not a direct factor as this approach assumes the toy being designed will be accessible to children of multiple ages through adding degrees of complexity with modular and multi-use components. The approach will take the form of a decision tree that will guide designers to add modularity and multifunctionality where necessary to extend the toy's lifecycle. Traditional methods of sustainability will be a background factor present while using the approach. This approach is best utilized once a core design intent for a toy is known. The toy category should be pre-determined, along with the decided age range the toy will be used by. Considerations for materials and play complexity may be determined in greater detail using the above research. This approach may be treated as a test to decide if modularity and multi-function pieces may be integrated during or after the initial design process, and before prototyping begins. Potentially, this approach may be used to determine how to create additional components or play that may be integrated into an existing toy. This approach may be tested multiple times on the same toy design with the intent to add as much modularity and additional functionality as possible, potentially scaling up designs originally intended for younger children for an older market.

4.2 Designing a More Sustainable Toy Using Modularity and Multi-Functions



Figure 67: Simplified Approach Flowchart

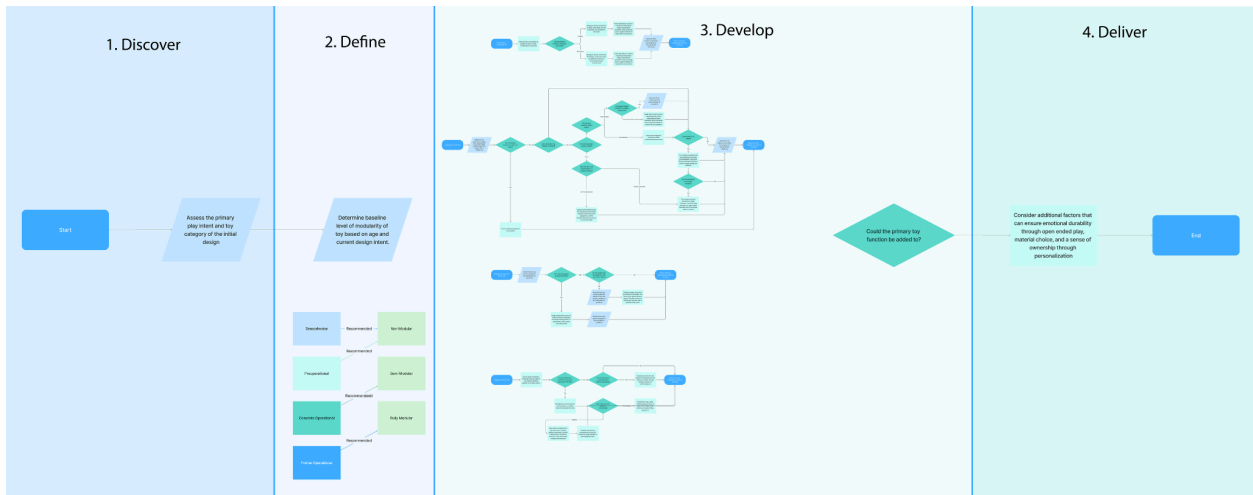


Figure 68: Comprehensive Approach Flowchart

1. Define the primary Toy Category

a. Construction Toy

- i. Modularity Requirement: By definition, construction toys involve pieces that must be interchangeable.
- ii. Decide if the main play is constructing itself or playing with the constructed result.

b. Game and Puzzle Toy

- i. Toys with a defined rule system or rigid construction path.

- ii. These toys have a set framing with a win or lose condition, and a goal to complete.
 - c. Plush Toys
 - i. Stuffed, sewn toys with inherent softness. Limited options for typical modularity and multi-use components, but unique opportunities for emotional bonding.
 - d. Other Toy Categories
 - i. Includes dolls, action figures, vehicle toys, creative/art toys, or outdoor toys.
 - ii. Have similar potentials for creating additional functions or elevated play scenarios with added components.
- 2. Predetermine a Baseline of Desired Modularity Level
 - a. Decide the Primary Age Category your Toy is for
 - i. Sensorimotor. Birth through 2 years old.
 - 1. Encourage the development of early, rudimentary motor skills as well as focusing on more basic activities relying on association rather than memory
 - 2. Use simplistic symbols to communicate general ideas rather than fully defined concepts.
 - 3. Recommended to be Non-Modular.
 - ii. Preoperational. Toddlerhood through early childhood (2-7 years old).

1. Encourage creative and personal expression with more developed symbols and representative objects
 2. Recommended to be Non-Modular in early phases of this stage, and possibly Semi Modular in the later development of this stage.
- iii. Concrete operational. Ages 7-11 years old.
1. Promote the development of logical reasoning through objects that are able to change in nature, have action-reaction effects, and represent more complex ideas.
 2. Recommended to be Semi-Modular, possibly Modular in the later development of this stage.
- iv. Formal operational. Adolescence through adulthood, 12 years and older.
- 1.
 2. Recommended to be Modular, but any level of modularity is acceptable.
- b. Primarily vs. Secondarily Modular
- i. Primarily Modular: The core play is building or assembling (e.g., LEGO).
 - ii. Secondarily Modular: Modularity supports a larger play goal (e.g., building a Hot Wheels track to watch cars race).
 - iii. Use these definitions to pinpoint how standardized and interchangeable your toy components must be.
- c. Fully Modular

- i. Every component is fully interchangeable using a standardized connection system (e.g., LEGO's "stud and tube" system). Every piece should ideally connect to every other piece to maximize creativity and reusability.
 - ii. Best suited for construction-focused play where the creation of the build is the primary play function, or at minimum used to enhance the primary play.
 - d. Semi-Modular
 - i. Uses a mostly standardized connection. Either each piece is modular but not every piece connects to each other, or the modular connections are standardized but not every component has connection ports.
 - ii. Works well when many pieces can connect, but the toy does not rely exclusively on total interchangeability.
 - e. Component Specific Modularity
 - i. A standard connector exists, but fewer components are truly interchangeable.
 - ii. Ideal for add-on accessories or expansions (e.g., action figures with universal hand sizes, toys with interchangeable parts).

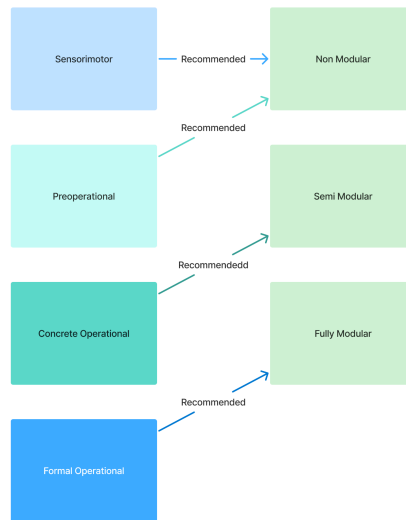


Figure 69: Age Range to Modularity Level

3. The Toy Design Process

a. If Designing a Construction Toy

i. Is Construction the Primary Play?

1. If yes, aim for a fully modular design. (See 2b)
2. Example: LEGO, where building is the central play mechanic.

ii. If Construction Is Secondary:

1. Consider secondarily modular or semi/partially modular. (See 2c)

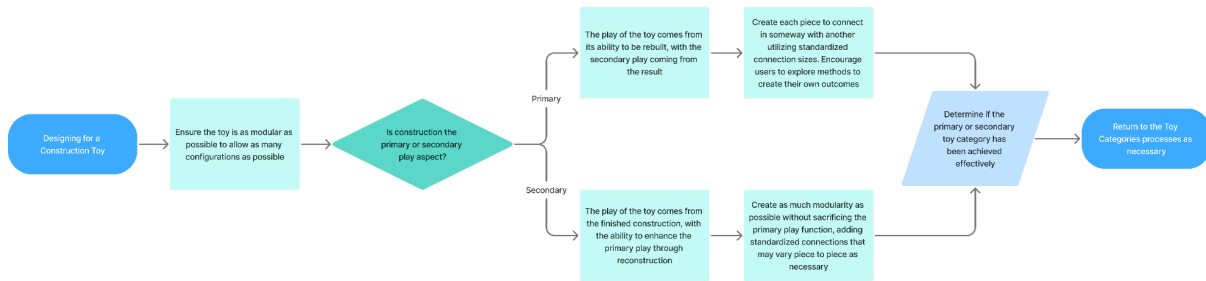


Figure 70: Step 3 Construction Toy Flowchart

b. If Designing a Game or Puzzle Toy

i. Aim for Multiple Game Settings or Puzzle Goals

1. If players can repurpose existing pieces under different rules, or the same rules with different pieces, the toy remains engaging for longer periods of time, and can be customized to suit new play desires.

ii. Add a Secondary Game

1. New rule sets, same pieces: reuse the original components for multiple games or puzzles by changing the rules and goal.
2. Design components in a way that their function can change based on context.

iii. Expand the Existing Game or Puzzle

1. New pieces, same core rule set: introduce additional pieces or expansions that alter the challenge or gameplay.

2. Interchangeable pieces that enhance the original game either through component specific modularity (see 2d) or through changing the context in which they are used

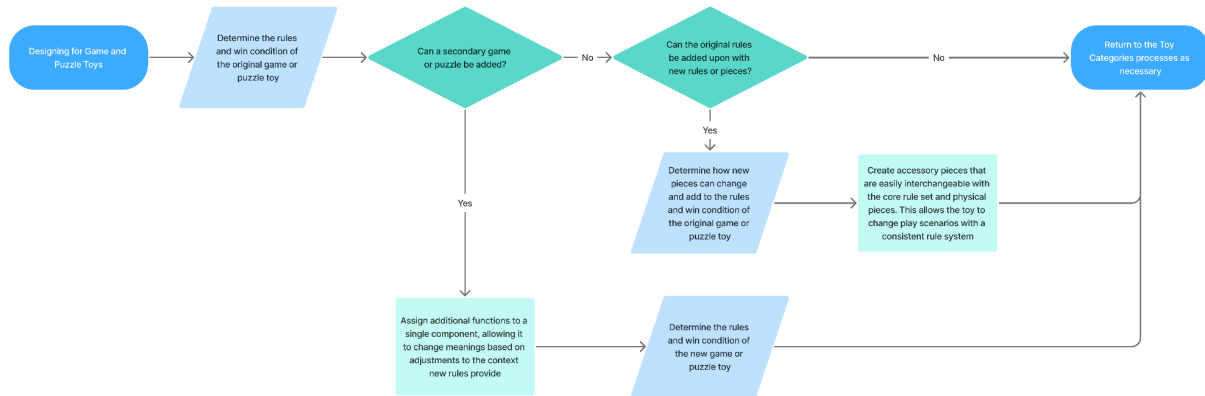


Figure 71: Step 3 Game and Puzzle Toy Flowchart

c. If Designing a Plush Toy

i. Recognize Unique Emotional Attachment

1. Children often sleep with plush toys, so the plush must remain soft, comforting, and safe.
2. Young children often take plush toys with them in several settings, so the plush must be durable.

ii. Explore Customization and Accessories

1. Consider clothes and reversible fabrics that allow the plush to change. Swappable outfits or small attachments that serve as

accessories can introduce fresh ways to engage without changing the inherent construction of the plush.

2. Surfaces that children can customize, e.g. draw on and wash (e.g., Doodle Bear) allow the plush to be personalized in an impermanent way, giving it changing and lasting emotional durability.

iii. Incorporate “Creation” or “Maintenance” as Play

1. Stuffing the toy oneself or washing to erase customization becomes part of the play.

iv. Being part of the creation of the plush and maintaining it deepens the emotional connection to the toy.

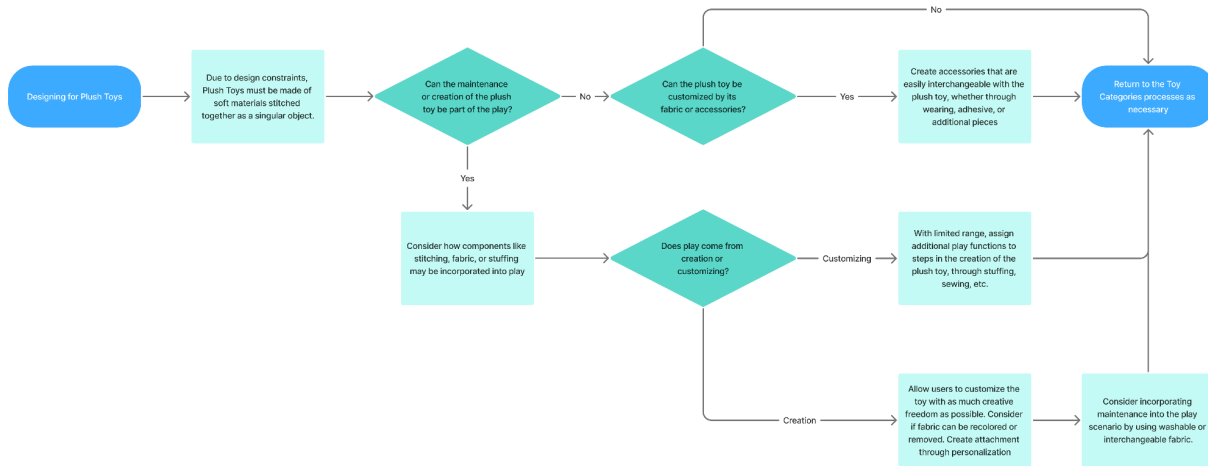


Figure 72: Step 3 Plush Toy Flowchart

d. If Designing Other Toys (Dolls, Action Figures, Puzzles, Vehicles, Creative, Outdoor)

- i. Check for Secondary Play Functions
 1. If you cannot add a new function, consider standard sustainability approaches (e.g., better materials, simpler repair).
 2. If you can add a second function, see if there is a second toy category or play scenario that can be added. (e.g., turning a vehicle into a playset).
- ii. Conversion and Transformation
 1. Partial Conversion: Implement simple manipulations (e.g., flips, rotations) to modify the components visually or through minor functional variations.
 2. Full Transformation: Shifting from one form to another (e.g., a bus transforming into a house)
 - a. Design the transformation process to be engaging and intuitive, possibly creating a similar experience to solving a puzzle, to enhance enjoyment and incentivize transformation.
 - b. Ensure that each configuration is fun on its own and offers unique play experiences to further incentivize transformation.
- iii. External Add-Ons
 1. Scope of Interchangeability: Decide whether interchangeability applies to the entire toy system or specific components.

- a. System-Wide Interchangeability: Refer to guidelines for secondarily/semi-modular designs to achieve full integration. (2c)
- b. Component-Specific Interchangeability: Implement strategies for customization, multi-purposing components, or accessories.
 - i. Customization: Create opportunities for personalization through a component's ability to be changed.
 - ii. Multi-Purpose: Design components that can be adapted for a variety of play scenarios to create versatility.
 - iii. Accessories: Create interchangeable components that alter the play through adding or removing while maintaining standardized connections.

- i. Options for personalized decoration, choice of modules, or self-assembly create a sense of “making it their own,” increasing emotional durability.

4.3 How to Apply the Approach

This approach may be utilized during any stage of the design process once a core toy intent and category is known. The approach can be completed with these simplified, ordered, steps:

Step 1. Start by determining the chosen toy category and play intent.

Step 2. Consider beforehand the targeted age demographic and whether or not modularity will be useful in the design as to make later modularity related decisions easier.

Step 3. Use the remaining steps decided by toy category to determine each presented option for the specific types of toys chosen, and if further solutions may be applied.

Step 4. Throughout, emphasize multiple play scenarios to foster emotional attachment and avoid early disposal. By designing toys that children want to keep and continue exploring, the product’s life span may be extended.

This process may be repeated at later stages in the design process by reassessing the toy, starting with Step 3, and running through the guidelines until the toy’s core design integrity would be compromised by adding further complexities. The Step 3 flowchart should be substituted as needed based on the chosen category from the options below.

Chapter 5 - Demonstration of Approach

To demonstrate the developed approach, a game toy was chosen due to the challenges of creating a physical board game that could be translated into a broader, modular toy outside of the original toy category without sacrificing the integrity of the core design. A board game provided a unique opportunity to create pieces as simple as possible that could be translated into multiple functions with standardized measurements. Using the

5.1. Initial Design Process

Following Step 1 of the approach, the initial concept for a game toy was further defined. The design intent started with a competitive, labyrinth style game where players compete to be the first to reach the center of a shifting maze. Each turn would consist of a player moving their token one space, and a wall tile one space in the attempt to slow other players.

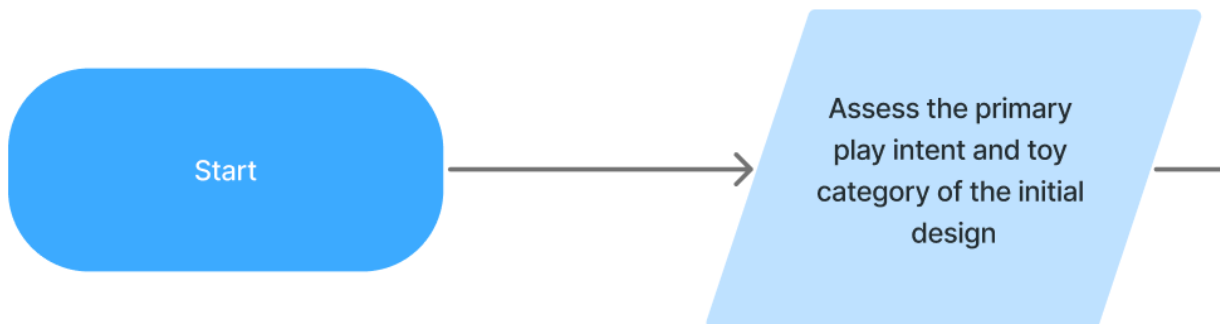


Figure 74: Step 1, Assess Primary Intent

This required at minimum wall pieces to shift around, a board, and at least two player tokens. Each piece was drawn to be a plastic component to be more durable and provide a tactile

experience. To avoid players immediately being trapped upon game start, a “safe zone” was added at the designated start point for each player token. Grass was chosen as a generic term for the safe zone tiles.

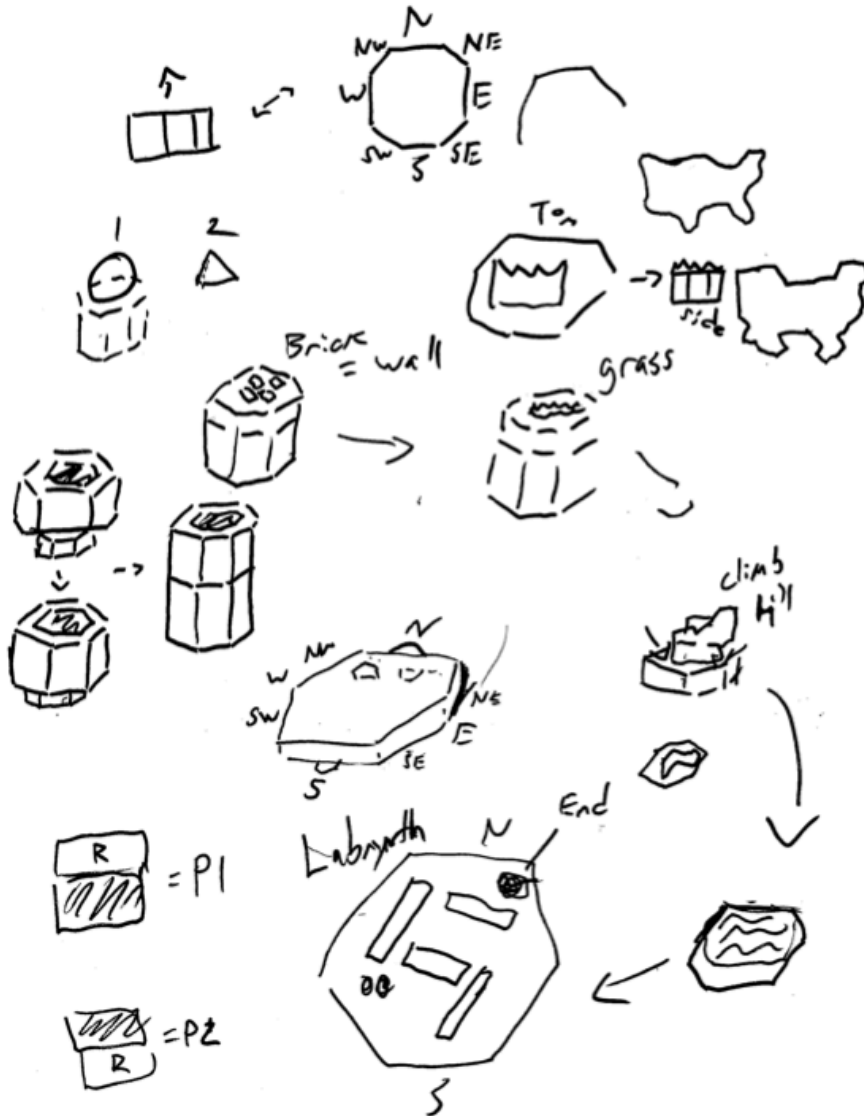


Figure 75: Initial Pen Sketch

The concept of a hazard tile was developed and water was chosen to represent it. To address Step 2 of the approach, it was decided that the game toy would be semi-modular so the physical board could be used by all pieces and be used by a range of ages dependent on the game version being played.

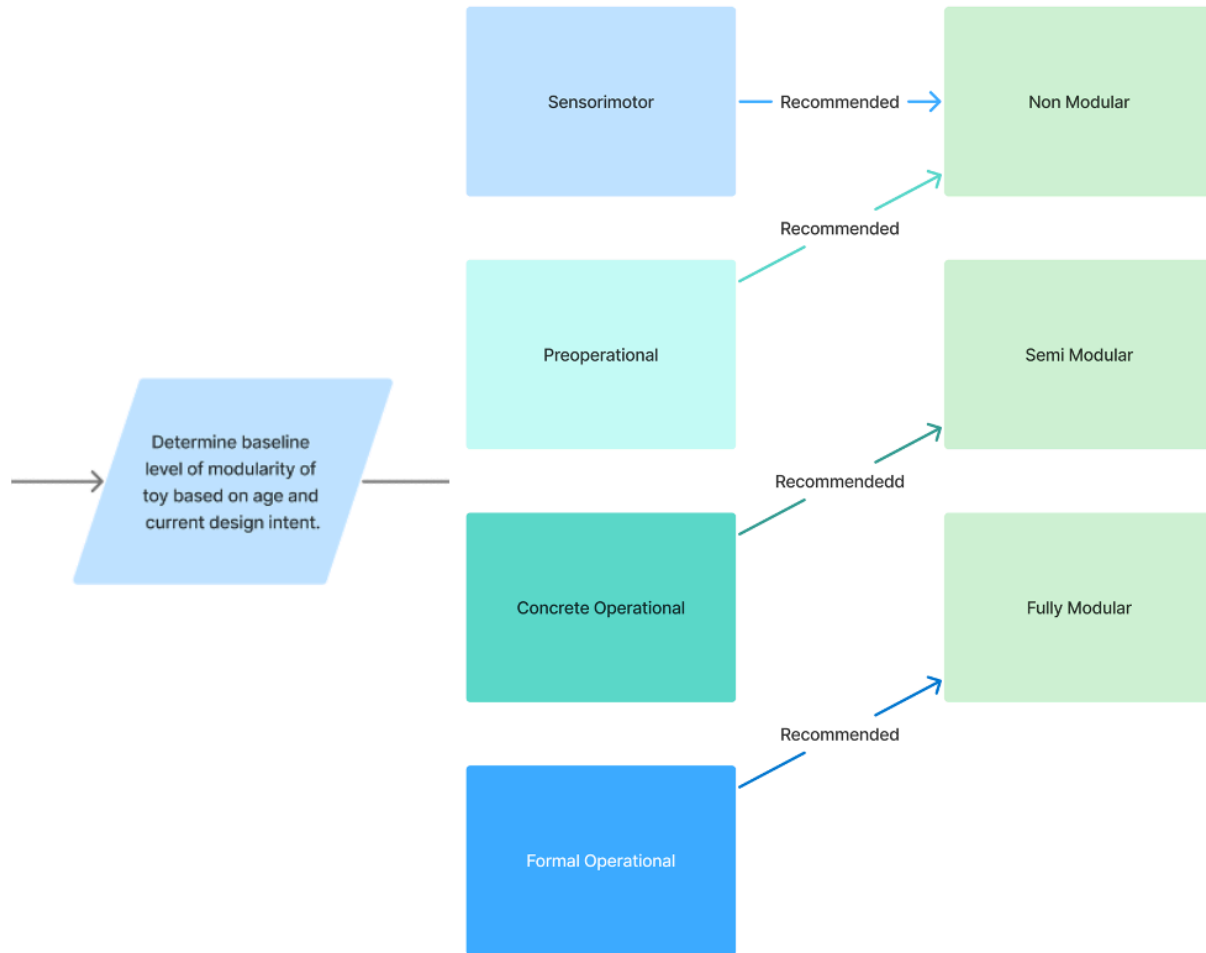


Figure 76: Step 2, Define Age Range and Modularity Level

With the intention of a customizable and shifting board already known, a standardized shape that could be stacked and slotted into another piece of the same shape was needed, opening the possibility of increasing its modularity later. To maximize board space and prevent unused area, the board had to be based on a simple polygon such as a triangle, square, or hexagon. A hexagon was chosen so that the pieces could have more dynamic movement across the board with six potential directions, as well as achieving a perfect tessellation, maximizing the area of the board with no rotations of the shape. The hexagons were shaped to be tiles with an indented center so as to be able to slot into other tiles, as well as the board.

Working in SolidWorks, the board was created first. Using the base shape of a 12" hexagon, tile slots were cut into the board at 0.175" apart, each 0.125" in height. The final board layout consisted of 91 hexagonal tile spaces. During the modeling process, the original slotted shape was reversed to allow a defined texture along the surface of each tile as well as the board.

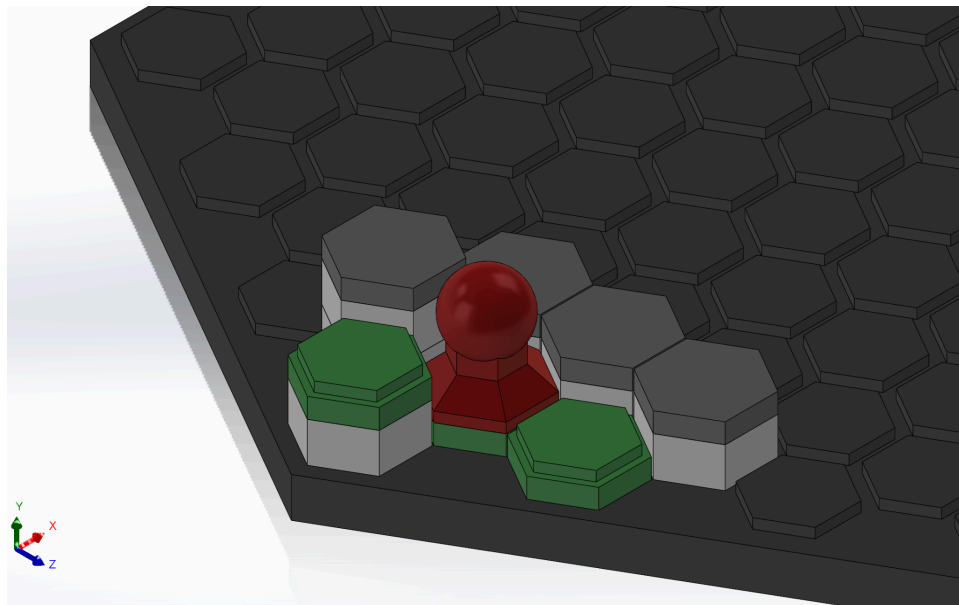


Figure 77: Initial CAD Model

This raised surface created the added benefit of the tiles being easier to grab, as well as differentiate by texture. Each tile was modeled to create a layer height of 0.25", with the raised and cut surfaces at 0.125", bringing the total height to 0.375".

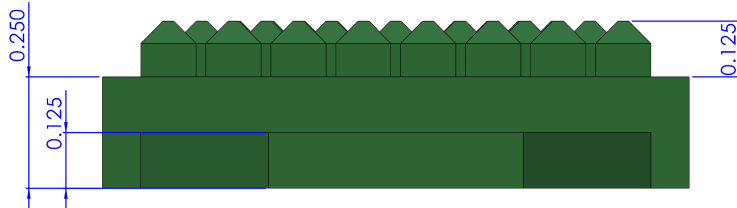


Figure 78: Tile Measurements

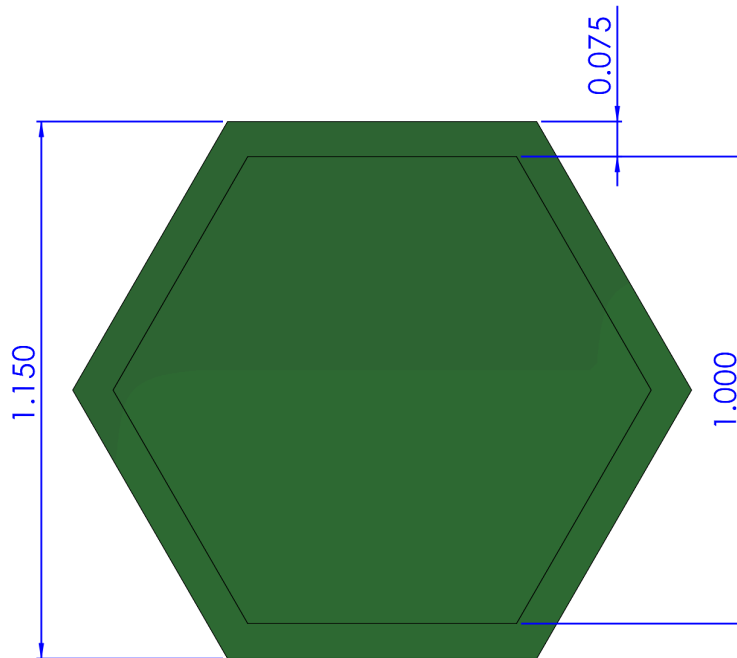


Figure 79: Tile Underneath

With the original intent of a labyrinth game known, the wall tiles were modeled to create a double layer height of 0.5", maintaining a consistent port of 0.125" for a total height of 0.625".

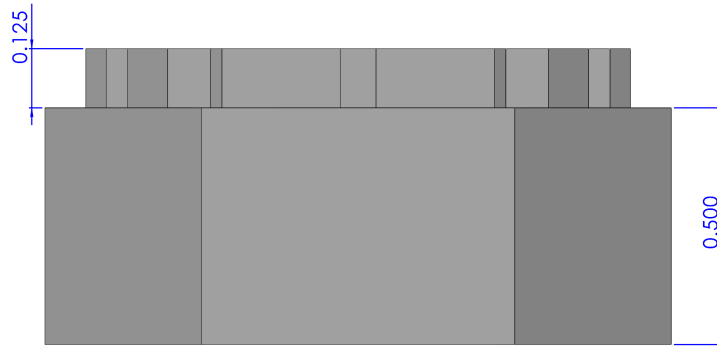


Figure 80: Wall Tile Measurements

The initial shapes of the tiles consisted of a grass “safe” tile, a water “hazard” tile, a ribbon “victory” tile, and a stone “wall” tile.

5.2. Application of Principles

To finalize Step 2 of the approach and with the intention of a shifting board known, the connection ports of each tile were already standardized and semi-modular, with each piece able to stack on top of another and build outwards provided they were on top of the game board. With this already in mind, a game toy was selected as the primary toy category in the Step 3 flowchart. With established, standardized tiles and an interchangeable board created, a secondary game could easily be added to the existing system. Within the context of the existing labyrinth game, there were only Four tile pieces, a board, and a selected number of player tokens. The original game was meant to be simple, each turn consisting of two actions to create a more complex board state. To preserve this design intent of simplicity, it was determined that reusing the simplistic components for future uses to be more fitting.

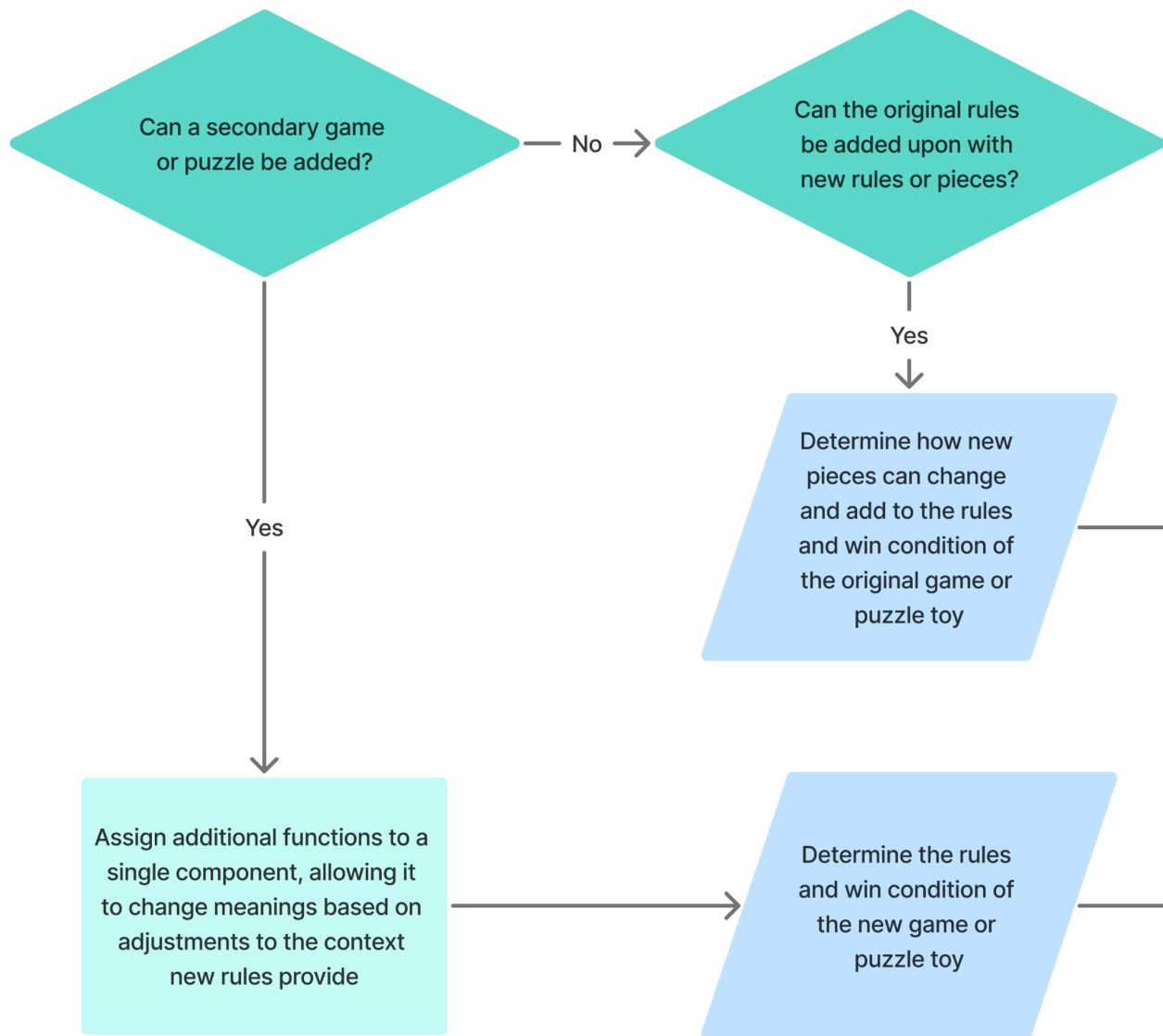


Figure 81: Adding a Secondary Game

To avoid creating small, complicated game pieces, the context of the game pieces were targeted rather than adding mechanisms to physically change them. The patterns along the tiles were

reshaped slightly with the intention to be generic enough so that they could more easily translate into the contexts of other created games for similar and separate uses.

With new design methods narrowed down, they could be applied to the game toy system as a whole. Small chamfers were added to the interior slot and exterior surface edges for users to more easily grab the tiles off of one another, as well as allow the tiles to more easily slide onto each other during board setup and gameplay. Additionally, the player tokens were set at a 1.5” height so that the top would always remain higher than the terrain pieces, making them easier to grab and move.

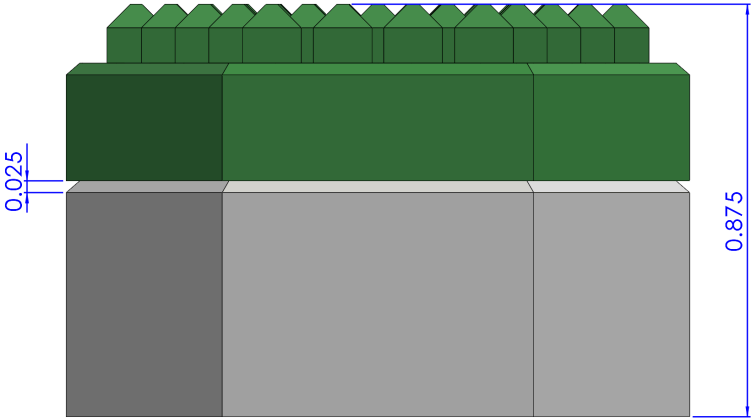


Figure 82: Stacked Tiles

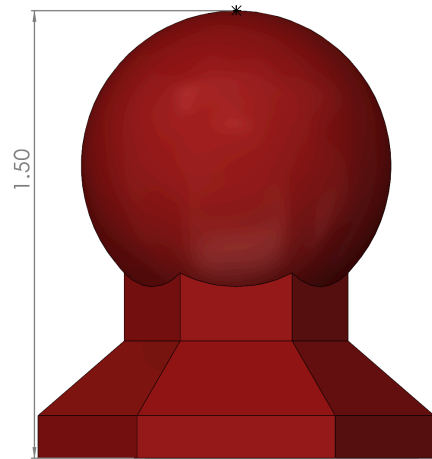


Figure 83: Player 1 Token

The original four tiles were revisited in concept to determine what else they could represent. For a secondary game, the design intent became a competitive race where players would roll dice and choose a path to follow to be the first to reach the end.

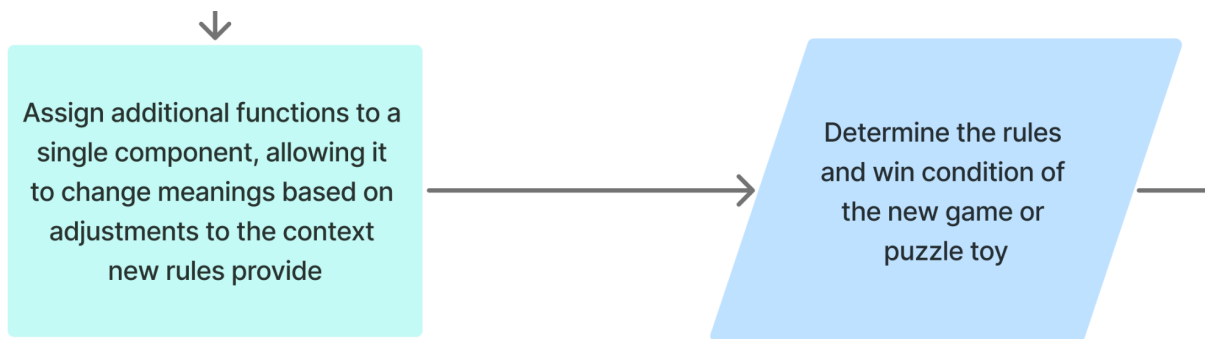


Figure 84: Developing New Rules

The grass tiles were chosen to represent a safe space, the water tiles chosen to represent a hazard where players would lose a turn, and the stone tiles chosen to represent a mountain where players would have to answer a trivia question to move forward, or else lose their turn.

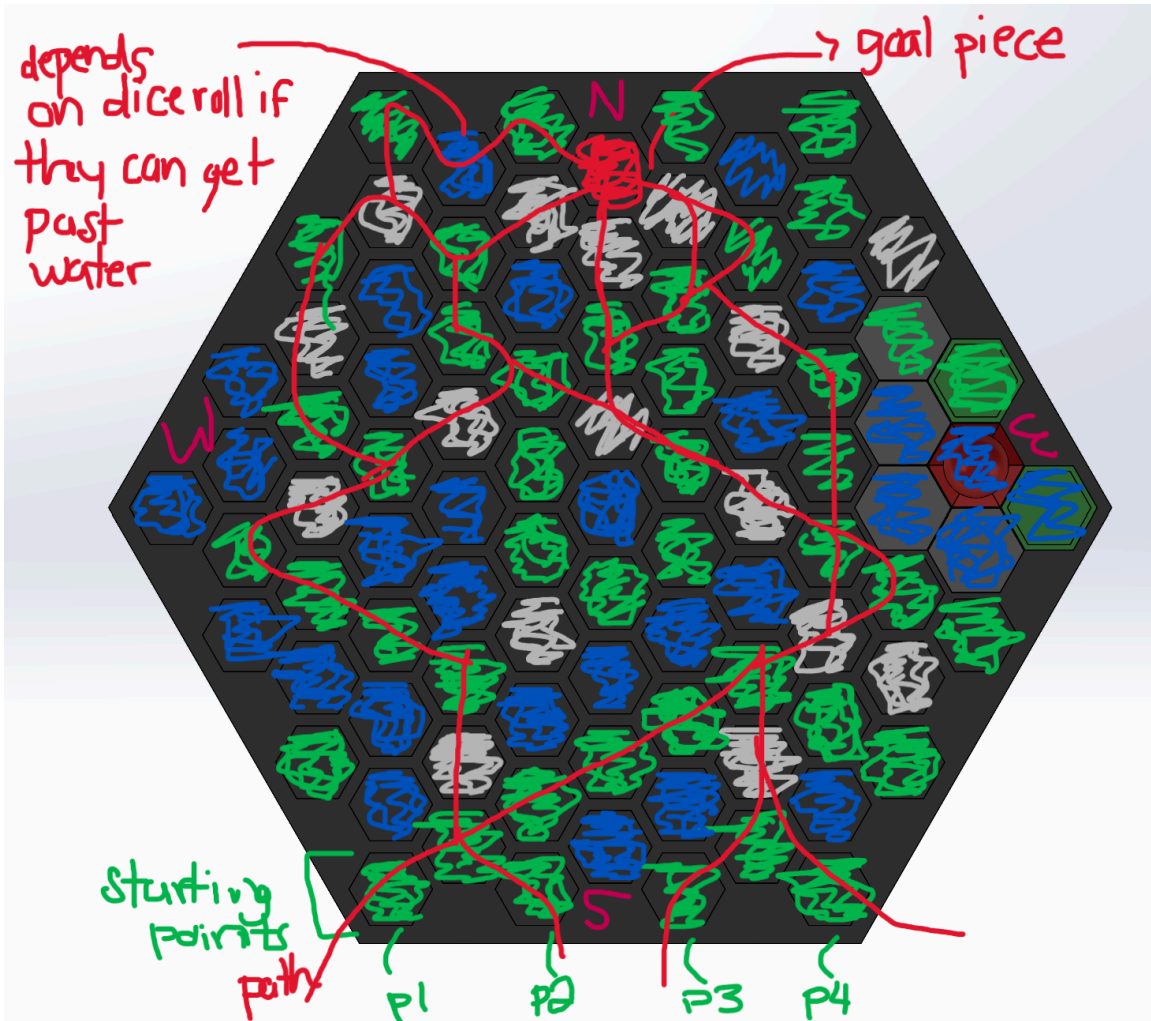


Figure 85: Trivia Game Board Sketch

To balance the paths equally, the shorter paths were given more “mountain” spaces and the longer paths given less with the intention of creating a risk reward interaction, where players could move faster provided they could answer more questions.

For a third game, the intended concept was a collaborative game where players would play against the changing board rather than each other. To push the meanings of the different tiles further, the game was designed as a “sailing” game where the group of players would seek to

reach the opposite corner of the board through teamwork. The water was chosen to represent an ocean, the grass chosen to represent a starting island, and the stone chosen to represent rocks in the water. A single player token would be used by the team, and players would collaborate to avoid rocks and create new pathways to the ribbon tile by placing water tiles on their turn.

5.3. Prototyping and Testing

With the modeled files of each component refined, they were then prototyped using PLA plastic and a 3D printer. 30 of each “terrain” tile (grass, water, stone) were printed along with a single ribbon tile, a single board, and 4 player tokens. Each file was automatically oriented within the slicer to minimize the material used by the printer and processed on the “fine” setting. The slicer software provided material use estimates for each component to be later analyzed in an LCA.

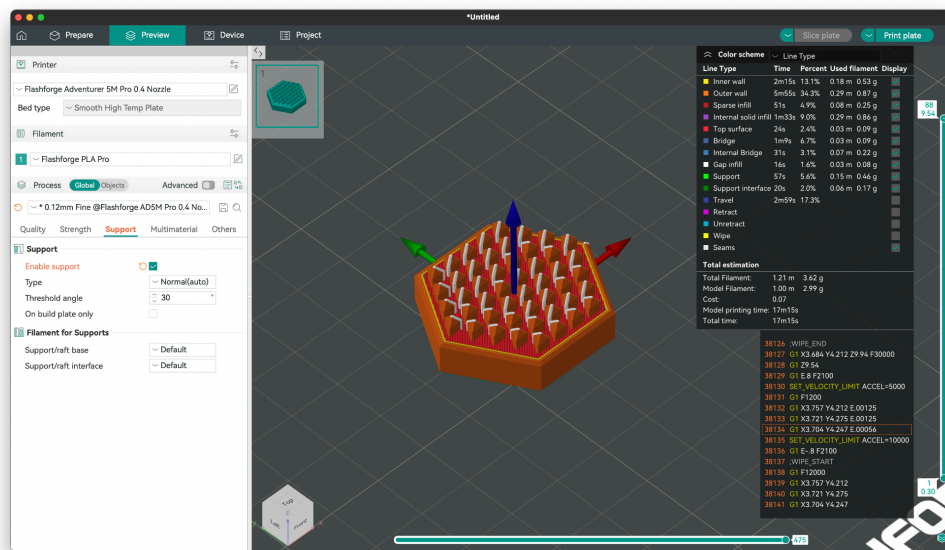


Figure 86: Grass Tile 3D Print File

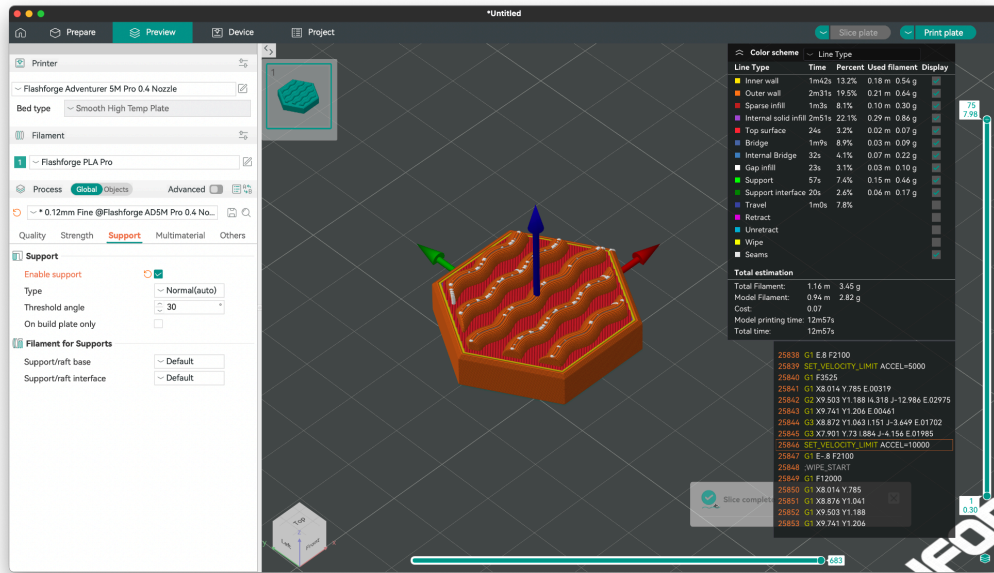


Figure 87: Water Tile 3D Print File

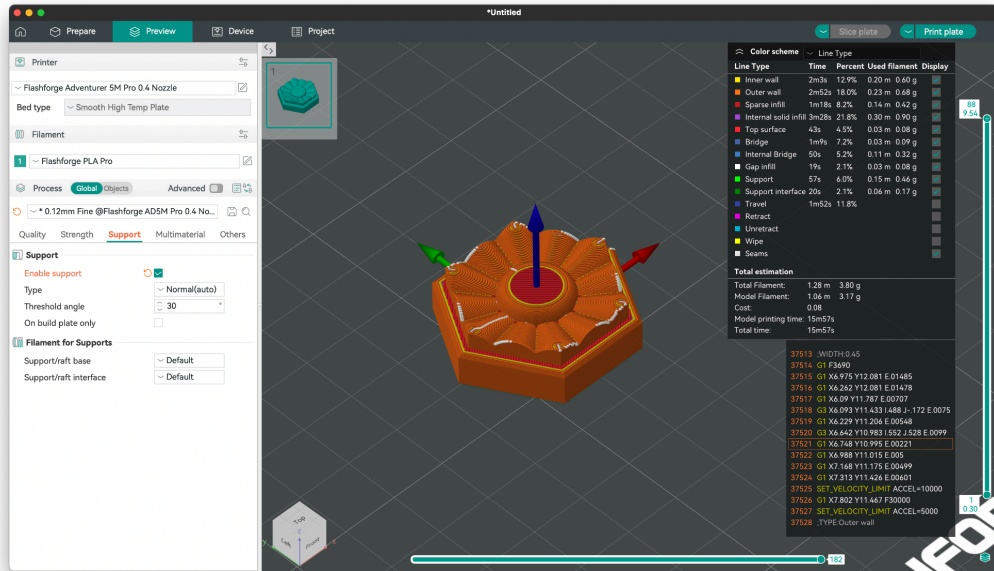


Figure 88: Ribbon Tile 3D Print File

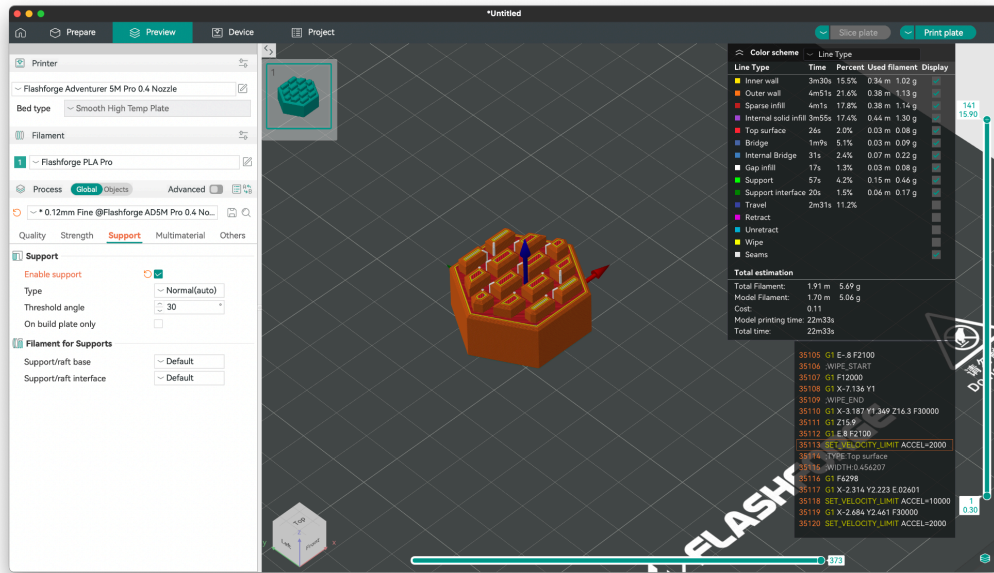


Figure 89: Stone Tile 3D Print File

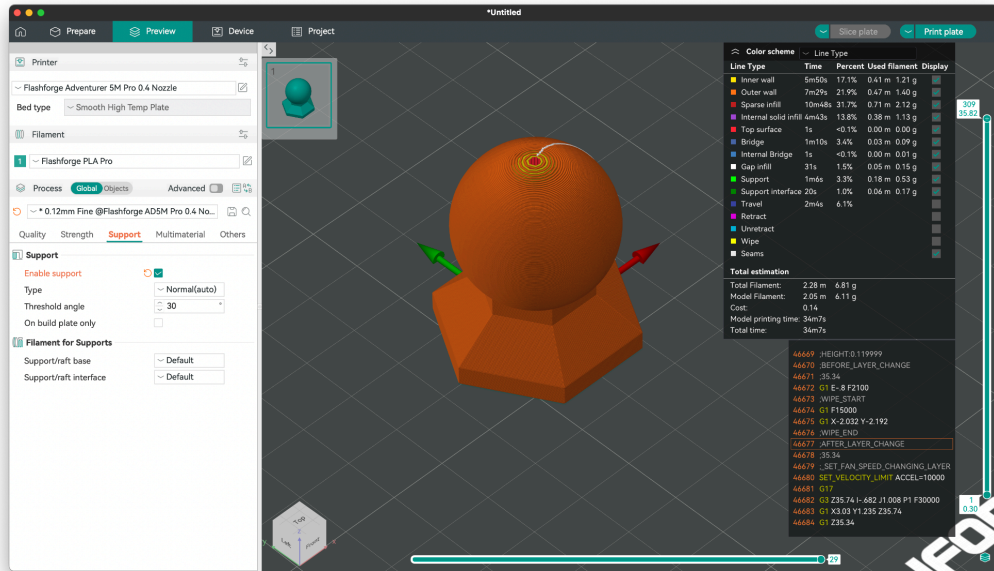


Figure 90: Player 1 3D Print File

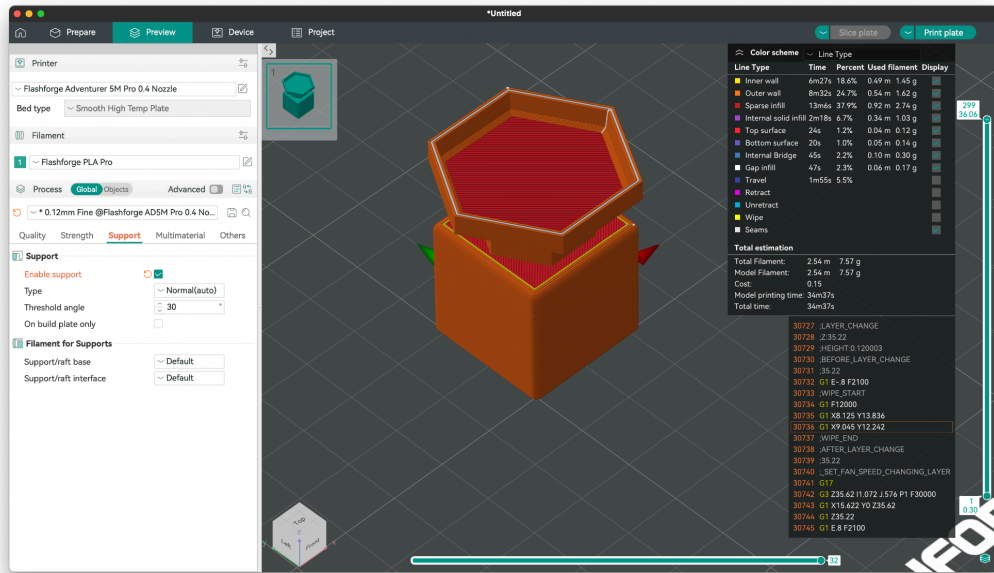


Figure 91: Player 2 3D Print File

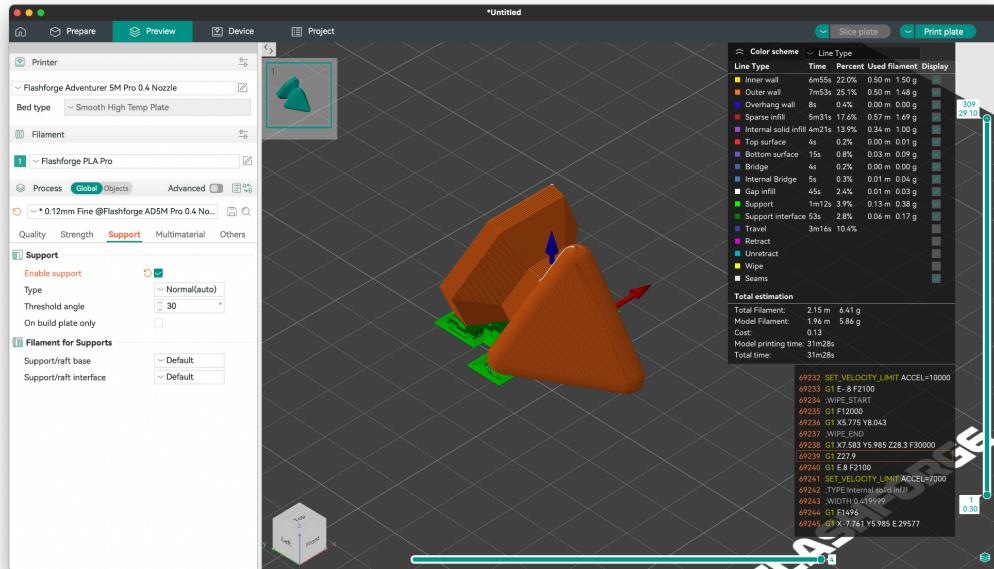


Figure 92: Player 3 3D Print File

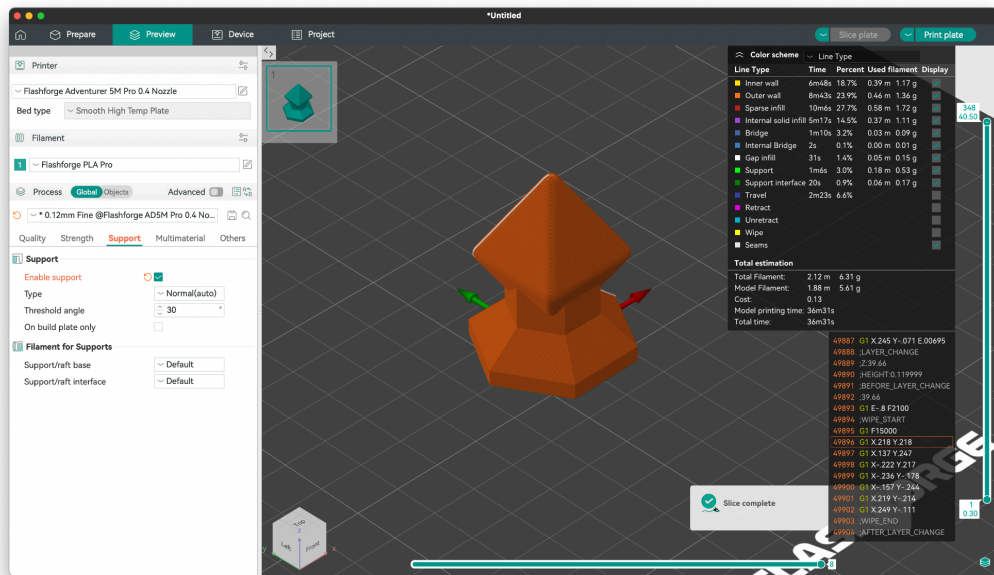


Figure 93: Player 4 3D Print File

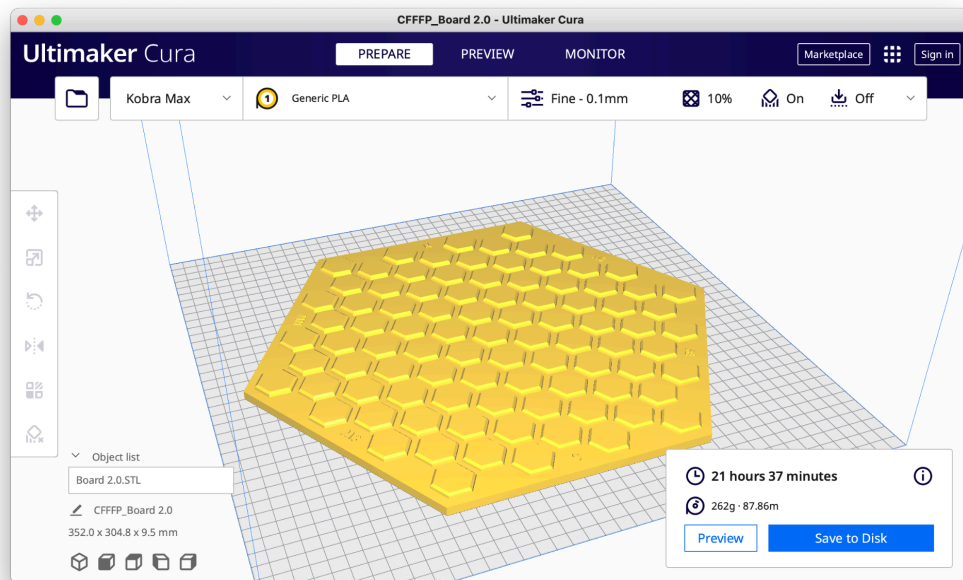


Figure 94: Board 3D Print File

This came to 91 tile pieces for the 91 space board, meaning that along with the 4 player tokens and two standard dice, the final piece count totaled to 98 pieces. Colors were chosen to match the representations of each tile, with green being grass, blue being water, gray being stone, and gold being the ribbon. For the PLA material, the colors were chosen to be harmonious and create a vibrant, pastel look against the dark board and stand out against the primary colored player pieces.



Figure 95: Materials Used

After the pieces had been fully printed and cleaned, the games could be tested to further develop the rules. At this stage, other designers were taken through the Step 3 design approach flowchart so they could create their own games and add to the base play functions of the game toy. Testing was done in collaboration with graduate students Kaitlin Coyle and Yeongwook Shin.

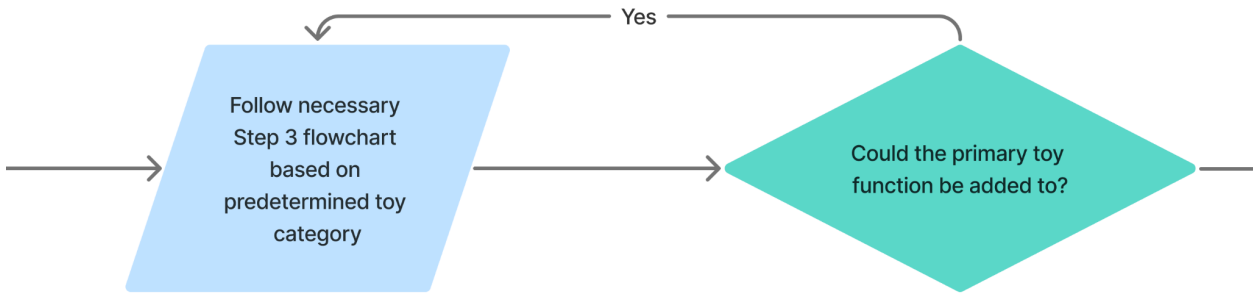


Figure 96: Repeat Core of Step 3

Each designer chose to reuse the provided pieces to create new games by adding additional context, framing, and a defined ruleset. Three games were created, one created by each individual tester to try and push the possible rules and play scenarios of the toy. Once the core rulesets were decided upon, the testers convened and refined the rules together.



Figure 97: Initial Testing

After the initial test, the textured patterns on each tile were changed to have a consistent edge height to create a more standardized connection point between pieces. With this change, a final version of the game pieces was printed and tested.



Figure 98: Ruleset Testings

The final prototype allowed for each ruleset to be fully developed through play-testing, allowing for a written rule set document to be written and the game toy to be analyzed as a finished product.

5.4. Final Product and Analysis

For the first game, stone tiles were placed in a repeated pattern around the board to ensure all players' starting turn had an equal chance to move a tile. Extra water tiles were added to the outermost edges of the board to prevent both player and wall movement to avoid players being completely trapped.

GAME #1: LABYRINTH

A maze game designed to test your strategy skills.
 Estimated game time: 10-15 minutes
 Ages 10+

Objective

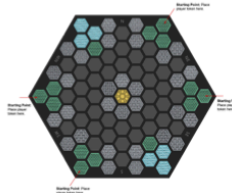
In the Labyrinth game version, players' objective is to find their way through the maze and reach the "victory" tile. Each player does this by moving "stone" tiles to clear a path for themselves or block their opponents.

Pieces Needed & Functions

- **Player tokens & Dice**
- 1 "Victory tile:" serves as the game "trophy."
- "Grass" tiles: serve as "safe" areas. These pieces are not movable and will stay in the same place throughout the gameplay. Players may move their tokens atop these pieces.
- "Stone" tiles: serve as obstacles. Players *cannot* place their tokens on a "stone" tile but are allowed to move the tile. "Stone" tiles may not be placed on top of "grass" tiles.
- "Water" tiles: serve as additional obstacles. "Water" tiles cannot be moved. Neither player tokens nor "stone" tiles can be placed atop "water" tiles.

Setup

Each player's token should begin at a start point as labeled in Figure 1. Starting points are 1) the corner between N & NE, 2) the corner between NE & SE, 3) the corner between S & SW, and 4) the corner between SW & NW. Compass directions are indicated by the raised N, NE, SE, S, SW, and NW marks on the gameboard. "Grass" tiles are required at all starting points.



Gameplay

- Ensure the game board is set up correctly (see Fig. 1). Each player should choose a corresponding starting point.
- Players should roll the dice to determine gameplay order. The player with the highest number goes first. Play proceeds clockwise.
- During each turn, every player has 2 actions. These may be done in any order:
 - a. **Moving their token:** Players must move their token 1 space on top of any nearby **grass** tile or unoccupied space.
 - b. **Moving a Wall:** Players must move a **stone** tile to any unoccupied adjacent space. Players are *not* allowed to move these tiles atop a **grass** tile.
- Repeat this gameplay until one player has landed on top of the **victory** tile. This player wins the game.

Figure 99: Labyrinth Ruleset

The second game was changed slightly to increase the risk reward interaction of taking shorter paths but having to answer more trivia. Empty tiles were chosen to be unplayable space to more easily distinguish the paths.

GAME #2: AROUND THE WORLD

A game designed to test your knowledge of world facts with a virtual add-on.
Ages 13+

Objective

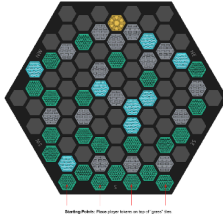
In the Around the World adaptation, the player's objective is to reach the "victory" tile by moving around the board as quickly as possible. Players roll a dice to determine the number of spaces they move each turn. Some spaces may require players to answer trivia questions. The game can also be adapted for teams of 2 with a maximum of 8 players (4 teams total), if desired.

Pieces Needed & Functions

- **Player tokens & Dice**
- 1 "Victory tile:" serves as the game "trophy,"
- "Grass" tiles: serve as "land" areas.
- "Water" tiles: serve as "ocean" areas and additional obstacles.
- "Stone" tiles: serve as "mountain" areas or obstacles.
- **Empty Spaces:** no gameplay is allowed on an empty space, players may only progress by moving on top of textured pieces (see Fig 2).
- Stopwatch or timer (a phone timer would work well)

Setup

The gameboard should be set up as illustrated in Figure 2, which outlines a path to the "victory" tile. Player tokens should be placed horizontally across 4 spaces on the South side of the board (indicated by the raised "S" mark on the board). These starting points should have "grass" pieces for players to place their tokens on top of.



Gameplay

1. Ensure the game board is set up correctly (see Fig. 2) and trivia questions have been downloaded. You can download a [Microsoft Word version](#) or a [PDF version](#).
2. Players should roll the dice to determine the gameplay order. The player with the highest number goes first. Play proceeds clockwise.
3. In the first round of play, the first player should roll the dice to determine how many spaces they will move. If a player lands on the following pieces:
 - a. **Grass:** Players are safe, and their turn doesn't require any other action.
 - b. **Water:** Players lose their next turn and must return to where their turn started.
4. The following rules apply for **stone** tiles.
 - a. Players must answer a trivia question correctly to pass over the **stone** tile.

- i. Even if a player does not land on a **stone** tile, but the tile is in their path, they are still required to answer a trivia question correctly to move forward.
 - b. Another player should read aloud a trivia question chosen by a roll of the dice
 - c. Once the question has been read aloud, the player has **10 seconds to answer correctly**; they should be timed using a phone timer or stopwatch.
 - d. If the player answers...
 - i. **Correctly:** they may move the number of spaces their dice roll indicated.
 - ii. **Incorrectly:** they must return to the space where their turn originated.
5. Repeat this gameplay until one player has reached the "victory" tile. This player wins the game.

Figure 100: Around the World Ruleset

The roles of the third game were tweaked so that each player could equally contribute to the state of the board and have an equal impact on the group's efforts. In the current version, on each turn the board changes to keep the gameplay dynamic.

GAME #3: VOYAGE

A cooperative game designed to test the partnership between players.
Estimated game time: 5–10 minutes
*3–4 players only
Ages 8+

Objective

In the Sailing game version, players' objective is to work together to create a path through the ocean to the "victory" tile. Each player will have a role—"Captain," "Sailor," or "Lookout." Players will work as a team to move one token to the "victory" tile.

Pieces Needed & Functions

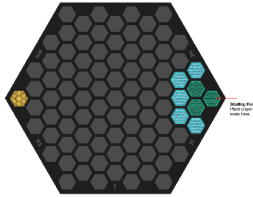
- 1 Player token and Dice
- 1 "Victory tile:" serves as the game "trophy"
- Grass tiles: serve as "land" areas. These pieces are not movable and will stay in the same place throughout the gameplay.
- Water tiles: serve as "ocean" areas and additional obstacles. The "Captain" may place the player token on any "water" tile that does not have a "stone" tile on top.
- Stone tiles: serve as "rocks" areas or obstacles. If a stone tile is placed on top of a "water" tile, the "Captain" cannot move to this space.

Setup

The gameboard should be set up as illustrated in Figure 3. The "victory" tile and starting point should be on opposite corners of the board—place the "victory" tile on the corner between SW & NW and the "grass" tile on the corner between NE & SE.

Roles

1. (1) **Captain** – they oversee moving the player token and always start the round.
2. (1-2) **Sailor** – they oversee building a path through the ocean that the Captain can follow. The path may be built *ahead* of whatever space the Captain's token is on.
 - a. **Note:** If playing with four players, two players will serve as Sailors.
3. (1) **Lookout** – they oversee removing "stone" tiles to keep the Captain's path clear.



Gameplay

1. Ensure the game board is set up correctly.
2. Players should roll the dice to determine gameplay order. The player with the highest number is automatically assigned the role of Captain. The player counterclockwise of the captain is the Lookout, and the remaining player[s] is/are the Sailor[s].
3. **During the Captain's turn:**

- a. The Captain starts the gameplay by rolling the dice *once*. They may move up to the number indicated by the dice roll or split their turn.
 - i. To split a turn, the "Captain" moves forward a select number of spaces and uses the remaining moves to place, *but not move to*, water tiles. They may split their turn anyway they would like.
 1. For example, if the "Captain" rolls a 6 they may split their turn by moving three spaces and placing three "water" tiles.

4. During the "Sailor's" turn:

- a. The sailor should roll the dice twice.
 - i. **On the first roll:** this determines the number of "water" tiles they can place on the board.
 - ii. **On the second roll:** this determines the number of "stones" they can place. "Stone" tiles can only be placed on top of "water" tiles.

5. During the "Lookout's" turn:

- a. They should roll the dice once. The number rolled determines how many "stone" tiles they can remove. When removing a "stone" tile, they must also remove the "water" tile beneath it.
 - i. The following additional rules apply during the "Lookout's" turn:
 - i. The "Lookout" may not break the path when removing "water" and "stone" tiles. There must always be a clear path to the starting point.
 - ii. If there are not enough "stone" tiles to remove on the "Lookout's" turn, they must remove "water" tiles to complete the number of moves indicated by their dice roll.
 1. For example, if a 5 is rolled and there are only 3 "stone" tiles, they must remove the "stone" tiles along with 2 "water" tiles.
- b. Repeat this gameplay until the "Captain" lands on the victory tile. This wins the game.
 - a. **Note:** if the "Captain" is near the victory tile they cannot split their turn to win. They must roll the *exact number* of spaces to land on the victory tile. They may split their move to get as close as possible to the victory tile but must still place water tiles during their turn.

Automatic Losing Condition

If at any point all "water" tiles become occupied by a "stone" tile, the players automatically lose the game and must begin again. Figure 4 illustrates an example of a losing game board; however, your game board may look different.

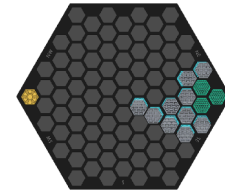


Figure 101: Voyage Ruleset

After playing each game, exploration began on if additional uses could be added to the current game system. With the existing terrain pieces, a small landscape map was built using the tiles as a kind of construction toy. Considering Step 4 of the approach, suggestions were made to create additional types of terrain tiles that could change gameplay and serve as add-ons to be purchased separately from the core game and create additional longevity through customization and personalization.



Figure 102: Board Mock Landscape

Using the material estimates from the printer slicer, a single use life-cycle assessment estimate was able to be completed, then comparing results to the prior examined game toys. While printed with PLA filament, if manufactured as a real product the toy would most likely be created using ABS plastic. The simplified LCA was done with this assumption.

Hex Board Game		
Material- ABS		
Grass Tile (30)	0.007980734 lbs	0.23942202 lbs
Water Tile (30)	0.007605948 lbs	0.22817844 lbs
Stone Tile (30)	0.0125443 lbs	0.376329 lbs
Victory Tile	0.00837757 lbs	
Player 1 Token	0.01501348 lbs	
Player 2 Token	0.01668899 lbs	
Player 3 Token	0.01413163 lbs	
Player 4 Token	0.01391117 lbs	
Board	0.577611 lbs	
Estimated Impact		
47x	1.4896633 lbs	70.0141751

Figure 103: Hex Game LCA

Because each piece was designed to be placed on any empty space on the board or stacked with each other, the Hex board game has a higher modularity ranking than other comparable game toys, but is not meant to be completely interchangeable like Beyblade X so is ranked slightly lower. On the other hand, the Hex board game is ranked higher than the other board games on play functions due to its ability to be reconfigured with new rulesets to play new games. While the Hex game has the highest impact score of any of the compared games, this impact can be significantly reduced by its lifespan increase from modularity and play functions.

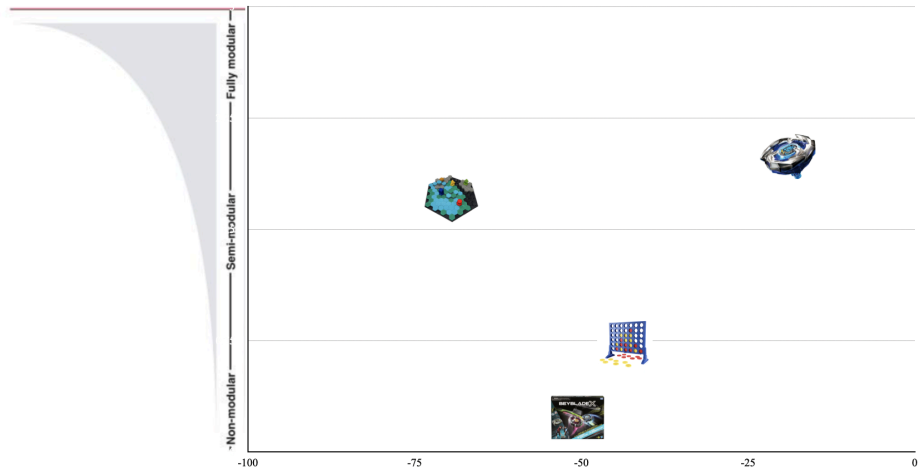


Figure 104: Updated Game and Puzzle Toy Modularity Ranking

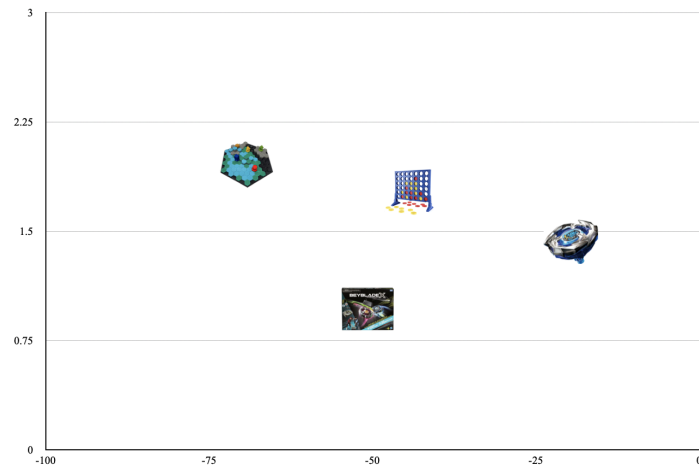


Figure 105: Updated Game and Puzzle Toy Play Function Ranking

6. Conclusion

Designers have a responsibility to consumers and society to design better, longer-lasting products. Cheaply made goods have a twofold impact on the consumers that use them as well as the environment once discarded. While plastic remains a dominant material in the industry, designers should focus on product longevity through traditional means of durability and creating more emotionally fulfilling experiences. This is especially true in toy design, where the product's lifespan is almost primarily determined by the positive emotions associated with it. Increasing a toy's functionality and personalization through methods such as open-ended design and modularity helps to lower a plastic toy's impact per functional unit following Okala's ecological guidelines. Despite being one of the higher initial impact toys, the Hex board game has a lower impact per functional unit when compared to current, on-market toys due to its interchangeability and open-ended design. While not realistic to add to every toy due to age or other design constraints, modularity, multiple functions, and open-endedness should be used whenever possible in toy design to strengthen the emotional attachment and create a variety of play scenarios to lengthen the product lifespan as much as possible.

Future Study

With limited resources, the design prototype could not be tested with more sustainable materials. Evaluating the existing prototype against a more sustainable version could prove valuable. Additionally, utilizing the approach tool to create toys from each category and evaluating those against market products would provide additional information on the efficacy of the decision tree.

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