A Systematic Analysis Framework for Toy Modularity

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Abstract. There are multiple approaches to achieving modularity in toys, each with its unique set of advantages and tradeoffs. In light of such variety, designers might find it increasingly strenuous to be constantly mindful of each set in teams that need to agilely develop new products to fulfill the swiftly changing market. Another challenge is that during the ideation phase in design exploration, the designer might find themselves limited in their understanding of modular toy design and miss certain possibilities that could be a result of random combinations of the different aspects of modularity. This paper aims to aid designers in both selecting concept direction before ideation and exploring random possibilities during ideation. By introducing a systematic analysis framework for toy modularity visualized in a graph with two axes, the graph can focus designers on the appropriate route while providing a vast map that they can readily explore. In addition, two examples are provided to ground the graph in real design projects and demonstrate how it can be utilized.

Keywords: Modularity, toy design, analysis framework.

1. Introduction

The concept of modularity in the realm of manufacturing has been met with serious interest in recent years. However, such a concept has been previously explored extensively by the toy industry due to the valuable benefits it provides for child development. The most successful demonstration of such exploration is the LEGO group.

The success of the LEGO group is often regarded as a triumph of business model innovation. Joachimsthaler, CEO of Vivaldi, noted the company's ability to utilize the interaction field to bring forth value to all of its stakeholders [1]. Still, there is the fact that such operations are only possible due to the flexibility that the LEGO "brick" provides [2]. LEGO is 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 [3]. Despite the LEGO "brick" being the most celebrated, it is not the only way towards toy modularity, and there exists different extends of modularity to be desired.

These different ideologies are fundamental when deciding the direction, a designer would like to embark upon after persona analysis, as each approach could be modified to fit specific needs and budgets. Having settled on an inappropriate path could cost the designer valuable time and resources before realizing that instead of tweaking and making compromises such that one path displays traits of another, taking an entirely different path would be more effective [4]. A great way to lower the possibility of ending up in such situations is to systematically evaluate the various ideologies against the persona developed and try to make an empathetic decision on behalf of the end-user.

This paper aims to provide a systematic approach for designers to evaluate different types of modularity and the tradeoffs of the various extents poses. In addition, two examples of modular toy design are provided to demonstrate how this approach can be applied to the design process. The backbone of the approach is a plane of two axes each with no discrete steps, it facilitates a substantial range of combinations to not limit the choices available to the designer. The designer could then evaluate the plane against the developed persona, eventually arriving at a coordinate that best suits the target user. Upon this, further development can be focused on the direction built upon the approximated values of each axis.

2. Definition

Modularity is defined 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 [5]. These two aspects are both part of the definition and criteria for evaluating the extent of modularity of a product [6]. 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.

With one axis based on the extent of modularization to be practiced, the other focuses on the type of modularity. Although modularity as a quality has been definitively defined, how a product displays such quality has not. The following extremes will be defined as the two vertices of the second axis, the type of axis:

Internal modularity: The toy itself is built to be modular, where the quality is displayed by each component of the product itself.

External modularity: The byproduct or side effect of the toy is modular, where the toy is essentially a factory for modular components which in turn bears the quality of modularization.

It must be noted that although semi-modular is defined as a midpoint on the extent axis, it does not display half of the modularity of a toy that is fully modular, nor does it require half the work needed to achieve full modularity. A non-modular toy can be easily made semi-modular by adding an interface and distributing a subset of functions to some of the components. However, a semi-modular toy needs to be extensively worked upon to displace all the functions into distinct components and design an interface that would allow components that vary greatly to interconnect.

Fig. 1 depicts the graphical illustration of modularity concerning the two axes defined above. The black horizontal axis denotes the extent axis, while the red vertical axis denotes the type axis. The quality of modularity is given as the gray area between the axes.

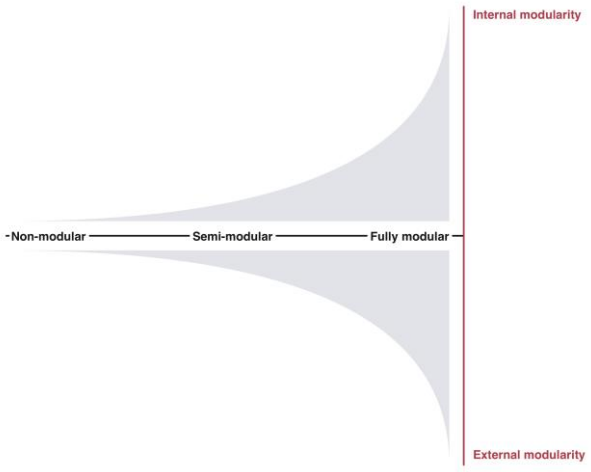


Fig. 1 The graph of modularity

3. Utilizing the Graph

3.1. Considering Child Development

Although it might seem easy to rush to the judgment that toy designers would naturally gravitate away from non-modular designs, some unique aspects of non-modularity deserve careful consideration, nevertheless. The limitations of a toy can be, to some extent, providing an artificial challenge for the child. When the child plays and is quickly accustomed to the known ways of playing, the incentive to develop new and innovative ways of play will increase simultaneously. The "think out of the box" mindset can be critical when it comes to children's intellectual development. Another benefit of non-modular toys is that they are typically extremely straightforward because a single component facilitates all the functions, and there's no need to consider interfaces that would add complexity to the play.

On the other side of the spectrum, fully modular toys could be more demanding for children as they typically require the child to be able to imagine the completed construction that has the functions of each component combined. The foresight is needed as each component no longer displays the full set of functions, instead, it only exerts a single function, and the child is left to select different functions of desire and utilize the provided interface to achieve the functions by connecting the corresponding components. This anticipation of an unseen product, similar to traditional construction sets, can be mentally demanding for the child [7]. The reality is that it is "hard to imagine what to do with the bricks" and navigating the interface can bring about similar motor, spatial, and early mathematical skills development to those provided by traditional toys [8]. This can enable a problem-solving challenge different from non-modular toys where the child tries to figure out creative ways to use a toy outside of its original ruleset [9]. Fully modular toys encourage the child to explore the limitations and possibilities inside the provided ruleset.

With the two extremes laid out, it becomes obvious that the extent in between, semi-modular, aims to capture the benefits of both ends. Being partially modular enables the toy to be playful enough to engage and capture the child's attention in a short period. When the child is attracted and has familiarized themselves with the current state of the toy, the modular aspect can help provide possibilities and encourage the child to actively imagine what potential lies within the toy. As modularity is limited, this also forces the child to be creative. In this case, the child is working with the ruleset of the toy when performing recombination and working outside the ruleset when exploring new ways of play.

All of the above are beneficial in the light of specific problems they impose.

3.2. Considering Costs

Along the type axis, the cost of the target user to gain access to each modular component becomes the defining variable. Such cost can then be assessed in two aspects, financial cost, and labor cost.

Due to the nature of external modularity, where the byproduct of the toy is modular, it naturally entails that the toy needs to have some sort of supplement, which can be naturally sourced or purchased as an add-on to the toy. The cost of extending a construct built with the byproduct components is directly concerned with the cost of securing the supplement. In addition, external modularity relies on the byproduct, which must be somehow produced by the toy itself through a specific process, such a process can be labor intensive, or it could be automated. The benefit of external modularity is that its supplement can typically be sourced from nature, substantially lowering the cost of attaining new components to sustain play. A great example is sand brick casting, where plastic brick-like molds are used to shape wet sand into bricks which can then be used to create different structures. On the contrary, since it is hard to maintain an intricate automated system when dealing with uncontrolled supplements from nature, these kinds of designs are typically manual instead of electrical. Which in turn denotes a higher labor cost for the target user to make the components of interest.

Internal modularity, however, does not provide the option of sourcing additional components from nature. The additional components must be purchased as the components are specifically designed and ought to have proprietary interfaces. This could potentially have a "lock-in" effect on the user as the already purchased components pose a sunk cost, and with the ever-extending construction, the demand for new components would be a sustained need. The benefit of such is that with careful design, the interface can be made precise and durable, while the user no longer has to do the work of attaining the components, instead the components are premade in factories.

The core difference between the two types of modularity is the question, "Who makes the components". For externally modular toys, the user must make the components, and for internally modular toys, the factory makes the components. Thus the cost of attaining new components would differ, but it must be noted that an automated externally modular toy with purchased supplements can be more expensive than an internally modular toy, such as a simplified electrical 3D printer with specific but expensive filaments. There is no definitive pattern of cost change along this axis, but the difference in cost should be considered when exploring different concepts in these two modular types.

3.3. Considering Demand

In recent years, products such as customed Everyday Carry (EDC) gear, Apple Watch's removable watch bands, and handcrafts have seen great demand as consumers increasingly crave individuality. This is a result of the collective growth of personal independence throughout cultures around the globe. In a paper by Sianturi and Fuad, they pointed out that modularity is key to addressing such increasingly varied needs. A great example is, again, the LEGO " brick" [10].

In a world where computers and robotics are emerging as basic tools for humanity, LEGO was able to quickly adapt to the moving tides and achieve great results by recombining the basic LEGO "bricks" such that it integrates the notion of robotics and programming [11]. This endeavor would require a company to develop different parts of the robot and perhaps come up with an interface that would allow the students to explore different mechanics. For LEGO, only the core module and a computer program are required to be developed, while other components can be sourced from existing factory lines. This greatly saves time regarding processes such as seeking approval or quality testing and development costs for designing and establishing manufacturing processes.

Modularity's benefit is enhanced by the fact that its ability to boost both engineering and learning capabilities [12]. Since engineering in essence is utilizing different components with unique functions and figuring out how to incorporate them using their interfaces. Learning is similarly reliant on the process of understanding components together with their functions and utilizing those learned in problem-solving or creative works.

When weighing the direction of a toy design, it is important to consider the benefits of modularity, while also noting that the interface of components is challenging to develop, to say the least. The LEGO "brick" took decades to perfect and have its interface thought out. A toy with adaptive and extendable interfaces might be more costly to design and implement than simply a non-modular toy. Such an interface would need to comply with the target user's needs and be fully certified such that it can take up the essential task of structurally interconnecting the different components.

4. Examples

The examples include an internally semi-modular toy and an externally fully modular toy.

4.1. Mr.Pip: An Internal Semi-Modular Toy

The first example is a pull toy designed for a typical 17-month-old boy named Tommy whose persona is shown in Fig. 2. Tommy is regarded as a child with a great tendency to actively explore and understand his surroundings, while his parents are looking to advance his motor skills.

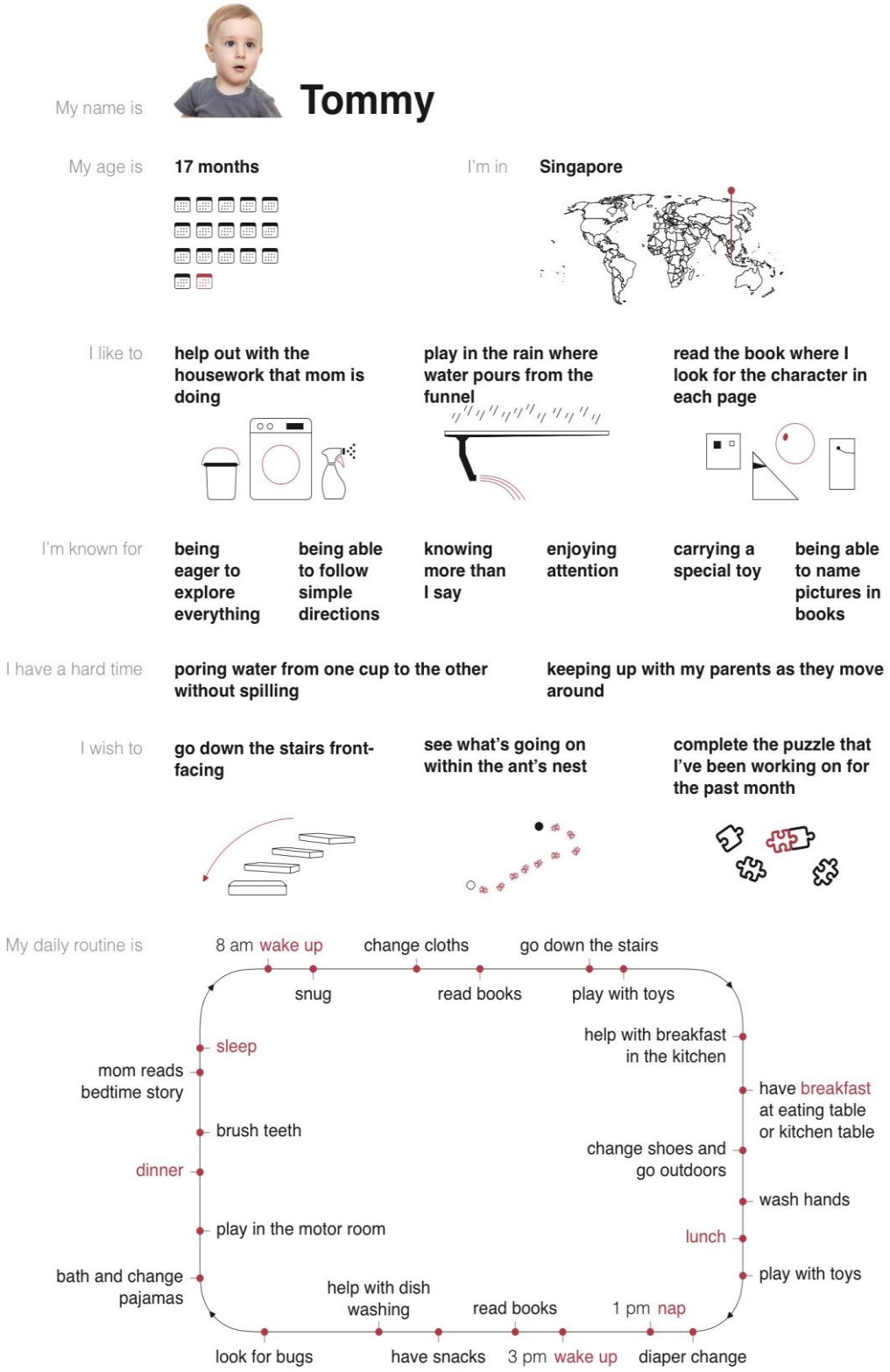


Fig. 2 The persona of the target user for a pull toy

Using the graph of modularity, it can be decided that in light of Tommy's age, mental ability, and motor skills development, a fully modular toy would be too complicated and entails too much mental stress, while external modularity can be either too complex if electrically assisted or too labor intensive if manual.

By ruling out some of the options, three internal modular concepts, one non-modular, and two semi-modular are developed.

Sphere: semi-modular, a caterpillar with spherical segments, each segment is supported with a single sphere that acts as both the main body and wheels. The spheres are removable and the segments can be disconnected.

Slice: semi-modular, different animals are being segmented into standardized slices and multiple slices can be attached to a trolley. The slices of different animals can be put together to create various new creatures.

Energy: A non-modular, mechanically driven electric generator outputs energy to power a bulb attached to the head of a dog-shaped pull toy. The case is transparent for the child to study the mechanics while connecting the concept of electricity with labor.

After exploring the three concepts, the sphere design was selected to be further developed. The next step is to distribute functionalities into different components and select an appropriate interface. Accounting for Tommy's age and motor skills, the interface must be able to be manipulated with ease but also provide strength. In light of such, the Fidlock HOOK buckle is selected due to its magnet-assisting alignment, together with woven nylon as the interconnect between segments and the buckle. Fig. 3 shows how the buckle simply snaps to align the teeth, which provides significant strength when interlocked.



Fig. 3 Demonstration of a Fidlock buckle interface between segments

Following the original concept, the wheel, body, and weight can be consolidated into a single component with some engineering. Upon further consideration, the handle should be a separate component for simple replacements to accommodate the child's physical growth. The result is shown in Fig. 4.



Fig. 4 The rendered design of Mr.Pip

As semi-modular provides a good compromise between fully modular and non-modular, the sphere concept, later given the name Mr.Pip, allows Tommy to easily start playing, while also permitting more complex operations made possible by the modular aspect:

Customization with different colored segments where Tommy can remove, add, or change the sequence of the body segments of Mr.Pip.

Exchanging segments with friends who may have possession of other colors.

Parents can attach more segments with the advancements of the child's motor and cognitive skills, where longer chains are harder to pull and navigate in the environment.

Participating in adversarial games where segments can be claimed when a child catches another during a chase. The more segments a child carries, the heavier the pull toy becomes. After some time, the child with the most segments will win the game.

To conclude, Mr.Pip is a good demonstration of an internal semi-modular toy, where rules of play can be made more flexible when compared to a non-modular toy, whilst being easy enough for 17-month-old Tommy when compared to a fully-modular toy. Internal modularity is preferred as Tommy does not have the excess energy or attention for an external modular toy.

4.2. Sand Printer: An External Fully-Modular Toy

The second example is a manual 3D printer that has sand as its filament. Designed as an outdoor toy for an active 10year-old boy Dan as in Fig. 5, the toy went through the same initial assessment procedure on the graph of modularity similar to Mr.Pip.

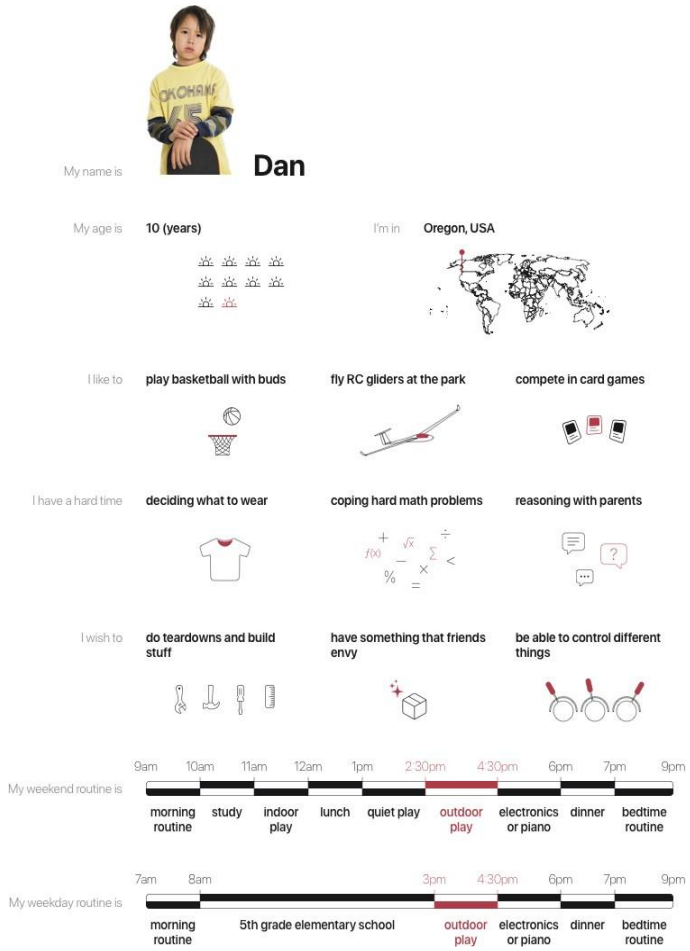


Fig. 5 The persona of the target user for an outdoor toy

As Dan has an interest in physical activities such as basketball and is open to the concept of building, a semi-modular or fully modular toy is well suited, without worrying about the labor involved in external modularity. Advancing in these directions, two concepts are developed:

Cubes: Internally fully modular, cubes that each have a single function can be interconnected to create a custom-built remotely controlled vehicle. The initial concept includes cubes that can act as a hot air balloon, wheel, camera, ship haul, processing unit, or structural connector.

Printer: externally fully modular, a 3D printer that is significantly simplified to be able to work with sand. Borrowing the idea from additive construction, the concept hopes to encourage children to think additively.

Although the cube concept initially showed great potential, its interface turned out to be much more complicated to design. Being able to connect watertight in all six directions without using male or female connectors that limit the direction of installation is extremely hard and would add a great amount of complication. Hence, the printer concept was carried along.

The printer works with sand, which upon being wet, could be extruded into infinite bricks that extend into long rectangular strips. Sand being a natural resource is freely accessible and would allow Dan to create huge structures without needing to consider fillament supply. Due to wet sand being able to stick together, external modularity is guaranteed where each strip of infinite brick can connect with other bricks.

However, sand being notoriously hard to isolate within compartments, demands that the printer is built with high tolerance and able to be easily dismantled for cleansing. To achieve this, the entire printer is designed to be constructed with a minimal amount of simple parts. Each part depicted in Fig. 6 can be separated and cleaned.

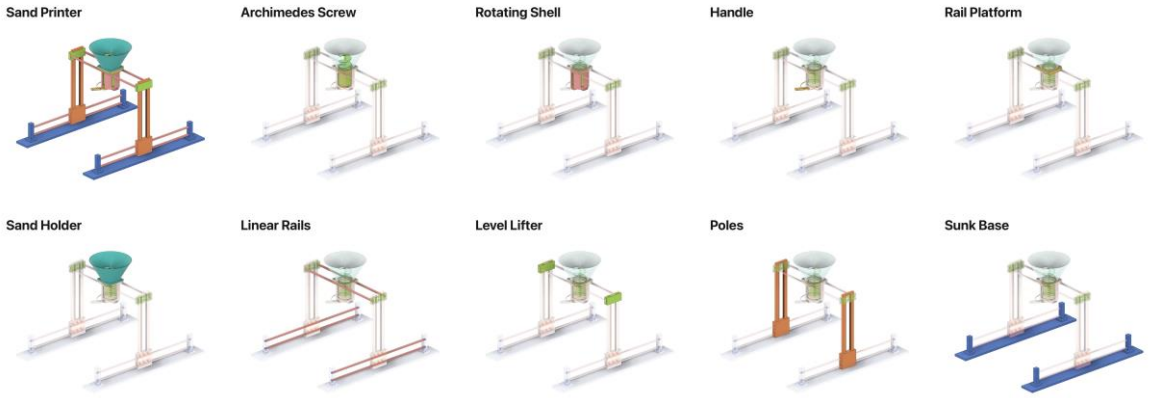


Fig. 6 The sand printer was built with a few simple parts.

Finally, using semi-translucent polycarbonate enables the visualization of sand filament and aluminum with ABS plastic to provide rigidity and endurance against salt water, which is typically near wet sand. The result is shown in Fig. 7 where the handle and level control buttons are colored with accent to give clarity for the operable parts.

At the core of the sand printer is the one-way bearing (Fig. 8), which is used to translate squeeze motion to one-way rotary motion [13]. This rotary motion, combined with the cavity and the Archimedes Screw will move and compress the sand from the collecting funnel to the extrusion head. The extrusion process is provided in Fig. 9.



Fig. 7 The rendered design of the sand printer



Fig. 8 One-way bearing translates squeeze motion into the rotary motion to perform extrusion.

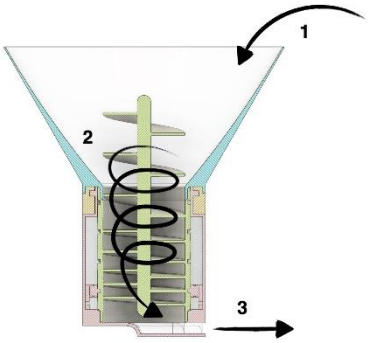


Fig. 9 The procedure of the compression and extrusion of the Archimedes screw

With time and resources critical to a typical company design team, the systematic analysis framework for toy modularity, which culminates in the graph of modularity, hopes to help achieve more thoughtful toys in a more agile fashion.

Different from Mr. Pip, the sand printer showcases the possibility of an external fully modular toy. Such a design decision will have great benefits of sustainability as it does not consume materials to build structures nor demands that components be prebuilt in factories.

5. Conclusion

Both examples provide great insight into how the graph of modularity can aid in the design process, where the direction can be determined without much effort by systematically going through the axes and evaluating against the target user.

The graph can be more than a tool to prune unrealistic development directions which saves time and resources, it can also provide a map for designers to explore different ideas. There can even be instances where the graph is printed out and a dice is randomly rolled. The designer can then come up with a concept that fits into the point specified by the point the dice stopped upon. This random evaluation technique could potentially aid in the exploration stage of the design process.

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