Overview

This following report offers a comprehensive overview and defines the scope of developing an innovative step ladder. It begins with primary research collection, involving semi-structured interviews. The subsequent synthesis phase integrates insights from these interviews, identifying key trends and challenges.

Engineering considerations are paramount, covering safety, durability, and functionality analyses. Social impacts are assessed through user experience evaluations, ensuring inclusivity and usability across diverse demographics. Environmental impacts are evaluated via Life Cycle Assessments, guiding eco-friendly design choices from material selection to disposal considerations. Clear design criteria and specifications are established based on research findings, informing the iterative ideation, prototyping (I, II, III), and design refinement stages. User feedback, engineering analyses, and sustainability goals drive continuous improvements in functionality and usability.

The report concludes by outlining future directions and potential enhancements, emphasizing ongoing efforts to advance ladder design, address user needs, and promote sustainable product development practices.

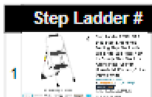
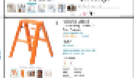
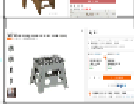
Primary Research Collection

Method

Semi-structured interviews were conducted to gather insights into students' opinions regarding step ladders/stools. It's important to note that the selection of students for these interviews was based on convenience, and therefore may not fully represent the entire student population or the broader user base.

During the interviews, a predefined set of questions (Appendix A) was utilized. Additionally, a Moral Alignment Chart (Appendix D) was employed, asking students to position different step stool/ladders according to the chart. Each image was assigned a number (Appendix C) for easy reference in the interview notes, ensuring clarity and consistency in data collection.

Results

Step Ladder #	Lawful Good	Neutral Good	Chaotic Good	Lawful Neutral	True Neutral	Chaotic Neutral	Lawful Evil	Neutral Evil	Chaotic Evil
1 	2			2	1		1	1	
2 	1	1		1		1	1	1	1
3 						2			5
4 	1		4	1					1
5 	1	1		1	1	1		2	

Interview Takeaways:

In addition to the classification above, students shared their commentary on the step ladders/stools. A few of the key points on each of the step stools can be seen on the right in the form of a word bubble (complete interview notes in Appendix B and E).

Aside from student commentary and the alignment of existing step stools, semi-structured interviews were conducted. Takeaways from these interviews can be found below.

<u>Takeaways:</u>

1. Users: Primarily individuals who require assistance in reaching elevated areas, including "short" individuals and children.
2. Pain Points: Notable concerns included stability, ease of folding/unfolding, and product durability.
3. Storage: Typically kept in garages, basements, or easily accessible spaces within homes, categorized as "houseware."
4. Use Cases: Ranged from routine household tasks like changing batteries or light bulbs to occasional needs for reaching high shelves or creating additional space.
5. Usage Frequency: Varied based on task frequency, with routine tasks performed approximately once a month and occasional needs addressed every six months on average.

Keywords:
handiwork; household objects; “short”; stability; habitual

Summary

Semi-structured interviews yielded valuable insights into the step stool experiences of a diverse group of Brown University students. These interviews, along with the categorization of five existing step stools, provided a comprehensive understanding of current opinions and common use cases. This data serves as a foundation for informed design decisions moving forward.

Primary Research Synthesis

Utilizing the data gathered from semi-structured interviews and the Moral Alignment Chart, an affinity map was constructed to categorize and analyze the various data points. This method allowed for a structured approach in identifying patterns, themes, and key insights derived from the interviews with Brown University students regarding step ladders/stools.

Identified Themes and Insights

1. User Demographics and Needs

All interviewees were current Brown University college students, however, the interviews highlighted that potential users primarily included individuals requiring assistance in reaching elevated areas, such as "short" individuals and children. This demographic insight is crucial for designing step ladders/stools that cater to diverse user needs and preferences. Pain points (referred to as “issues” in the affinity map above) such as stability, ease of folding/unfolding, and product durability emerged as significant considerations for users. Understanding these pain points informs design criteria aimed at enhancing user experience and safety.

2. Usage Context and Frequency:

The storage and use cases of step ladders/stools were predominantly categorized as "houseware," indicating their integration into everyday household tasks. This claim is supported by the extensive data points under “Use” that mention storing in garages, kitchen, sheds and so on. Usage frequency varied based on task importance, with routine tasks performed approximately once a month and occasional needs addressed every six months on average. This data aids in designing products that align with users' frequency of use and storage preferences.

3. Key Keywords and User Feedback:

Keywords such as handiwork, household objects, "short," stability, and habitual were frequently mentioned, reflecting users' priorities and expectations from step ladders/stools. Feedback from potential users provided insights into specific pain points and preferences, highlighting areas for improvement and innovation in ladder design. Detailed below are design specifications that came about after reviewing all data collected.

Design Criteria and Redesign Rationale

Based on the in-depth analysis of data streams, several clear design criteria and redesign rationales emerged:

- Stability Enhancement: Given the emphasis on stability as a pain point, design modifications should focus on enhancing ladder stability through improved structural design and material selection.
- Durability Improvements: Addressing concerns about product durability requires robust engineering solutions and quality assurance measures.
- Safety Features: Incorporating additional safety features to prevent incidents, such as falls from step ladders, is imperative to enhance user safety and confidence.
- Ease of Use: Redesign efforts should prioritize ease of folding/unfolding, ensuring user-friendly operation and storage convenience.

The synthesis of primary research data through affinity mapping and analysis has provided valuable insights into user preferences, pain points, and usage patterns related to step ladders/stools. This comprehensive understanding serves as a foundation for defining clear design criteria and redesign rationales aimed at addressing user needs and improving product usability and safety.

Engineering Considerations

To create a step ladder or stool that is safe to use and built to suitable standards for a wide range of users, specific considerations need to be taken into account. There are organizations dedicated to creating these standards and the engineering standards for step ladders and step stools include specifications for the physical product as well as its use. The following document provides a detailed view of the engineering considerations for step ladder and step stools such as construction, positioning, and usage. The standards listed were identified through the following institutions and authorities:

- OSHA (Occupational Safety and Health Administration)
- The American Ladder Institute

1. OSHA

As a government agency, the Occupational Safety and Health Administration (OSHA) sets and enforces standards for safe and healthful working conditions for workers in the private and public sectors.[1] According to OSHA, any ladder must meet the following specifications [2]

1. Step ladders should not be loaded beyond the maximum intended load for which they were built, nor beyond their manufacturer's rated capacity.
    a. A ladder will fail if it is loaded beyond the maximum intended load. Modes of failure include breaking and collapsing; both which can harm the user.
    b. The amount of weight a ladder can hold is dependent on factors such as materials, design, and type of ladder.[3]
        i. The following is a very rough list of materials in terms of strength, from strongest to weakest: fiberglass, aluminum, wood, and plastic.
        ii. A robust design will be able to withstand higher loads. The designs that make use of braces, rivets, and bolts will be stronger than those without
        iii. Depending on the primary use of the ladder, there is a different duty rating
2. Rungs, cleats, and steps of step stools of the base section of extension trestle ladders shall be not less than 8 inches apart, nor more than 12 inches apart, as measured between centerlines of the rungs, cleats, and steps.
3. Rungs, cleats, and steps of most portable ladders and fixed ladders (including individual-rung/step ladders) shall be spaced not less than 10 inches (25 cm) apart, nor more than 14 inches (36 cm) apart, as measured between centerlines of the rungs, cleats, and steps.
4. Ladder rungs, clear, and steps should be parallel, level, and uniformly spaced when the ladder is in position to use.
    a. One of the most common causes of ladder incidents is improper ladder set up[4]; this includes incorrect angle set-up which prevents the detailed position
5. The rungs and steps of portable metal ladders shall be corrugated, knurled, dimpled, coated with skid-resistant material, or otherwise treated to minimize slipping.

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[1] *About Osha*. Occupational Safety and Health Administration. (n.d.). https://www.osha.gov/aboutosha
[2] *1926.1053 - ladders.* Occupational Safety and Health Administration. (2014). https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.1053
[3] Martin. (2023, October 20). *Ladder load capacity: Understanding weight limits*. Laddercode, All Rights Reserved. https://laddercode.com/how-much-weight-can-ladder-hold/#:~:text=This%20can%20be%20dangerous%20and%20can%20cause%20the,ladder%20for%20the%20weight%20you%20need%20to%20carry.
[4] Centers for Disease Control and Prevention. (2024, March 1). *Newsroom feature: Ladder safety niosh*. Centers for Disease Control and Prevention. https://www.cdc.gov/niosh/newsroom/feature/ladder-safety.html

    a. Improper ladder use, including slipping is one of the top 5 leading causes of ladder incidents
6. Wood ladders shall not be coated with any opaque covering, except for identification or warning labels which may be placed on one face only of a side rail.
7. The minimum clear distance between side rails for all portable ladders shall be 11½ inches (29 cm).
8. The top or top step of a stepladder shall not be used as a step.
    a. One of the main reasons for ladder incidents is misuse of the ladder
    b. NIOSH says to "never step above the second highest step on a step ladder or the fourth highest rung on an extension ladder."
9. Ladders shall be used only on stable and level surfaces unless secured to prevent accidental displacement.
    a. A study completed by the American Ladder Institute cited the ladder not being placed on firm, level ground as one on of the most common causes of ladder incidents[5]
10. Maintain good housekeeping in the areas around the top and bottom of ladders

2. The American Ladder Institute

The American Ladder Institute (ALI) is a non-profit organization dedicated to promoting safe ladder use.[6] Ali serves as the ANSI ladder standard developer.

1. Step ladders must not be used unless their base is spread fully open and the Spreaders locked. Step ladders are not to be used as Single Ladders or in the partially open position.

The standards stated above were all considered during the design process although peer-reviewed papers on the issues they address are not currently available. It is important to note that there is a difference between step ladders and step stools. The majority of literature found on the safety of either is primarily focused on step ladders and ladders used under working conditions; for example, in construction. Despite not being directly applicable, literature on step ladders and work ladders was used in great detail to inform the design of the step stool. Literature on materials and loading were informative and transferable to our design needs.

Societal Impacts

The design and engineering process of step ladders significantly impacts society, particularly in terms of ensuring user safety, addressing ergonomic risks, and promoting transparency across the supply chain. These social impacts are underscored by insights gleaned from various studies focusing on accident modes, human behaviors, and the overall user experience associated with ladder usage.

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[5] Institute, A. L. (2024, January 16). *5 most common causes of ladder incidents*. The ANSI Blog. https://blog.ansi.org/ali/common-causes-ladder-incidents/

[6] *Ali Mission - American Ladder Institute*. American Ladder Institute. (n.d.). https://www.americanladderinstitute.org/page/Mission

Safety emerges as a critical societal need in ladder design and engineering, as highlighted by research on accident modes and injury patterns.[7] Studies reveal that falling is a prevalent accident mode, leading to a range of injuries. Additionally, non-fall execution errors and pinching incidents contribute significantly to injury patterns, emphasizing the imperative for designs that prioritize user safety and minimize accident risks.[8] Implementing conspicuous safety warnings and clear usage guidelines becomes crucial in mitigating accidents caused by unsafe practices.

Ergonomic considerations also play a pivotal role in addressing societal needs related to ladder design.[9] Research on ladder set-up behaviors and ergonomic risk factors demonstrates the importance of proper ladder angles, stability, and user-friendly designs.[10] By incorporating ergonomic principles into ladder design, such as considering human factors like strength, balance, and coordination, designers can enhance user comfort and reduce the likelihood of accidents due to ergonomic issues.

Furthermore, promoting transparency across the supply chain is essential for meeting societal expectations regarding ethical sourcing, fair labor practices, and overall accountability. Understanding the underlying causes of accidents, such as at-risk behaviors and non-compliance with safety guidelines, underscores the importance of transparent communication and education regarding ladder usage. Manufacturers can contribute to a safer working environment and reduce accidents by providing clear safety instructions and ensuring that equipment meets safety standards.[11]

The insights gathered from studies on ladder fatalities, ergonomic risk factors, and human factors associated with ladder use provide valuable knowledge about societal needs and social impact considerations in ladder design and engineering. These examples highlight the multifaceted nature of societal needs, ranging from safety and ergonomic considerations to transparency and ethical practices. Addressing these social impacts through responsible design decisions and user-focused approaches is paramount to creating step ladders that enhance safety, usability, and overall societal well-being.

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[7] Rapp van Roden, E. A., George, J., Milan, L. T., & Bove, R. T. (2021). Evaluation of injury patterns and accident modality in step ladder-related injuries. *Applied Ergonomics*, *96*, 103492. https://doi.org/10.1016/j.apergo.2021.103492

[8] Chang, W.-R., Huang, Y.-H., Chang, C.-C., Brunette, C., & Fallentin, N. (2016). Straight ladder inclined angle in a field environment: The relationship among actual angle, method of set-up and knowledge. *Ergonomics*, *59*(8), 1100–1108. https://doi.org/10.1080/00140139.2015.1115897

[9] Shepherd, G. W., Kahler, R. J., & Cross, J. (2006). Ergonomic design interventions – A case study involving portable ladders. *Ergonomics*, *49*(3), 221–234. https://doi.org/10.1080/00140130600576454

[10] Masory, O., & Rink, S. B. (n.d.). *Step ladder instability and dynamic loading*. fau.edu. https://www.fau.edu/engineering/directory/faculty/masory/pdf/step-ladder-instability-and-dynamic-loading.pdf

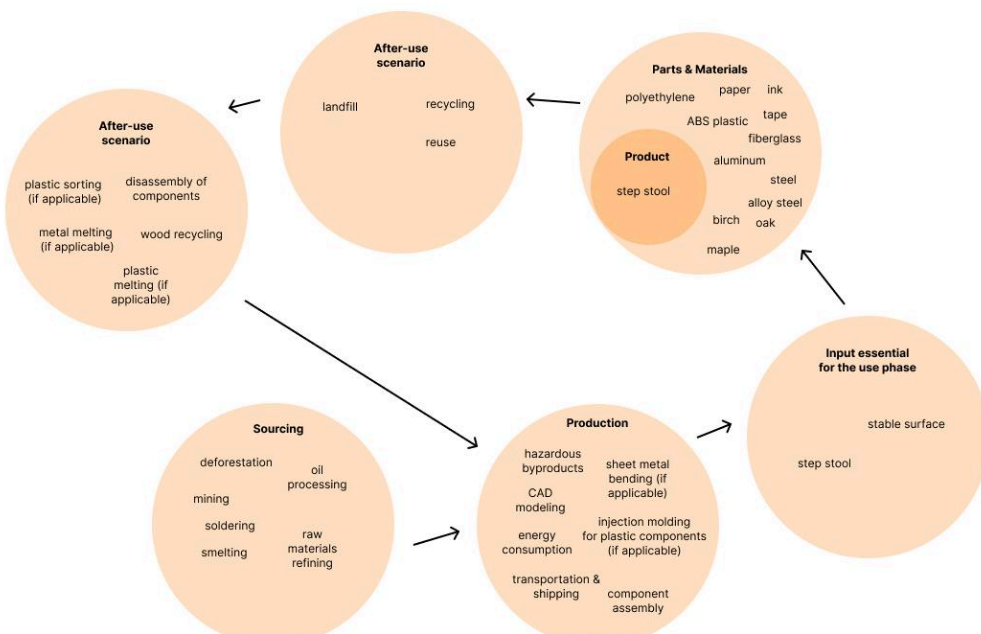
[11] Grant, A. T., & Hinze, J. W. (2013). Underlying causal factors associated with construction worker fatalities involving stepladders. *Construction Economics and Building*, *13*(1), 13–22. https://doi.org/10.5130/ajceb.v13i1.3133

Environmental Impacts

To investigate the potential environmental impact of our design, a circular journey map as well as a life-cycle assessment was conducted based off of an existing step stool that can be found in the market.

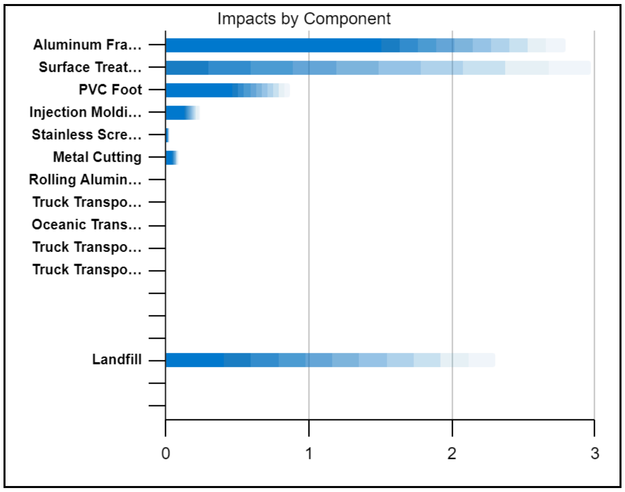
The circular journey map provides a holistic view of a product's lifecycle from sourcing to after-use, allowing designers to identify potential environmental issues at each stage. In the sourcing phase, environmental impacts such as resource depletion, habitat destruction, and water pollution can arise from the extraction of raw materials. The production phase often involves high energy consumption, greenhouse gas emissions, and waste generation, especially if unsustainable manufacturing practices are utilized. After-use considerations include product disposal challenges, such as limited recycling options or improper waste management leading to landfill pollution.

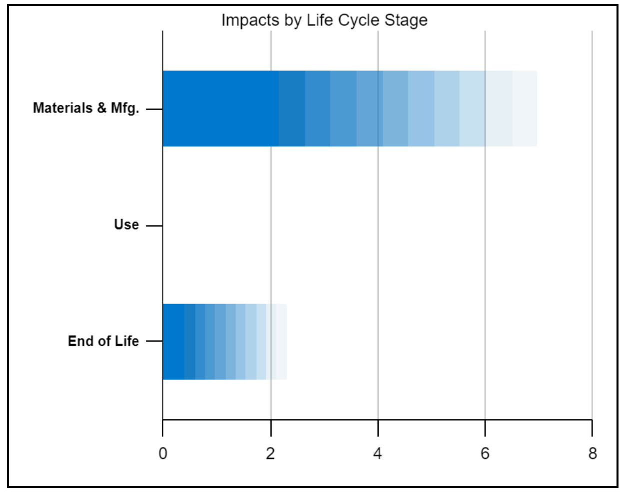
Analyzing the circular journey map, we observe that the busiest stages of a step stool's lifecycle are sourcing and production, indicating significant environmental footprints during these phases. Conversely, the use phase appears less demanding environmentally, with minimal input and impact.



A more sustainable design approach would involve targeting environmental hotspots in the sourcing and production phases, such as implementing eco-friendly materials, optimizing manufacturing processes for efficiency and waste reduction, and exploring circular economy principles for product longevity and recyclability. By addressing these issues comprehensively, we can extend the lifespan of products, reduce overall environmental impacts, and promote a more sustainable product lifecycle.

To comprehensively assess the environmental impact of a step stool's lifecycle, a detailed life cycle assessment (LCA) was conducted across all stages, including sourcing, production, use, and end-of-life.





The LCA findings, depicted in the accompanying graphs, reveal the magnitude of environmental impact across different lifecycle stages. The graphs include uncertainty shading to account for variations and uncertainties in data inputs and assumptions. Consistent with the conclusions drawn from the circular journey map, the LCA highlights that Materials and Manufacturing stages contribute significantly to the overall environmental footprint of the step stool, with substantial resource consumption, emissions, and waste generation observed during these phases.[12] This underscores the importance of sustainable material sourcing, efficient manufacturing processes, and waste reduction strategies in mitigating environmental impacts.

Additionally, the LCA identifies End-Of-Life considerations as another critical aspect, emphasizing the need for either proper disposal and recycling practices to minimize environmental burdens associated with product disposal[13], or to lengthen the use phase altogether.

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[12] Milovanoff, A., Posen, I. D., & MacLean, H. L. (2020). Quantifying environmental impacts of primary aluminum ingot production and consumption: A trade‐linked Multilevel Life Cycle Assessment. *Journal of Industrial Ecology*, *25*(1), 67–78. https://doi.org/10.1111/jiec.13051
[13] Author links open overlay panelJoost R. Duflou (1) a, Milford, R. L., Cooper, D. R., Misiolek, W. Z., Tekkaya, A. E., Haase, M., Widerøe, F., Boin, U. M. J., & Paraskevas, D. (2015, April 27). *Environmental assessment of solid state recycling routes for aluminium alloys: Can solid state processes significantly reduce the environmental impact of aluminium recycling?*. CIRP Annals. https://www.sciencedirect.com/science/article/abs/pii/S0007850615000591?via%3Dihub

Design Criteria/ Specification

Our journey in developing a step ladder has been guided by a thorough analysis of primary and secondary research data. Following this comprehensive analysis, the following design specification table was created; it encapsulates the essence of our findings and insights. This table serves as a distilled representation of the key design criteria, prioritizing elements based on their significance and relevance derived from the data at hand.

Design Requirements	**Requirement Source**
Step Stools should accommodate diverse users in all spaces.	Rosyidi et al. (2023); Pliner, E.M., et al. (2020); Tiedemann et al. (2007); Duraj, V., Fathallah, F. (2020)
Step stool should be portable and easy to lift.	User Interviews
Step Stools should fold & unfold safely and easily.	User Interviews
Stool should be able to transition between phases of life to promote longevity of product	User Interviews
Step stools should have strong stability (e.g. use a splayed base).	Shepherd, G. W., et al. (2006)
Step ladder feet should be flexible rubber with serrations and incorporate an attitude pad such that contact area is maximized.	Shepherd, G. W., et al. (2006)
Step ladders and ladders should not be placed at too shallow an angle (less than 70°).	Shepherd, G. W., et al. (2006)
Step ladders should be secured incorporate methods that secure them and are fixed to the ladder (e.g. lashing, straps, ladder stay, or builders hook);	Shepherd, G. W., et al. (2006)
Step ladders' rung spacing of 26.7 cm leads to lowest perceived exertion.	Duraj, V., Fathallah, F. (2020)
Reducing step height and providing forward lean support for fall prevention.	Pliner, E.M., et al. (2020)
Step ladders should not cause discomfort in knees, wrists, shoulders, or the lower back.	Rosyidi et al. (2023)
Step ladders should not exasperate limited vision and everyday pain.	Tiedemann et al. (2007)
Step ladders should employ stiff materials to avoid torsion	Step Ladder Instability and Dynamic Loading
Step ladders should use a wide stepping surface and allow for leaning for support	Human Stability on Step Ladders
The ladder material should match environmental/use case requirements	https://www.americanladderinstitute.org/page/Ladders101

In addition to the engineering considerations detailed above, the design requirements table details the specifications on design, as opposed to construction, that the interviews and secondary research pointed to. Below is a detailed view of the factors we prioritized when designing a step stool.

1. Safety:
    - Accommodating Design: Ensuring that the step ladder design accommodates diverse users, including those with mobility challenges, to promote safe and accessible use. Secondary research revealed that many existing step ladders are not accommodating for certain activities and are the cause of existing issues in mobility at work and out.

- Sturdy Construction: A step ladder should have a sturdy and stable design, such as using a splayed base and secure attachment methods, to prevent accidents and injuries during use. Primary research revealed that step stools that are currently used tend to be “wobbly” and made out of plastic which makes users “a little worried about it being flimsy.”
- Fall Prevention: Incorporating features like forward lean support and optimal rung spacing to reduce fall risks and enhance user safety. Many incidents mentioned during interviews involved users falling from a step stool/ladder and others revealed they wouldn’t use one because they would “fear for [their] life, [as the] second one is way too tall.”

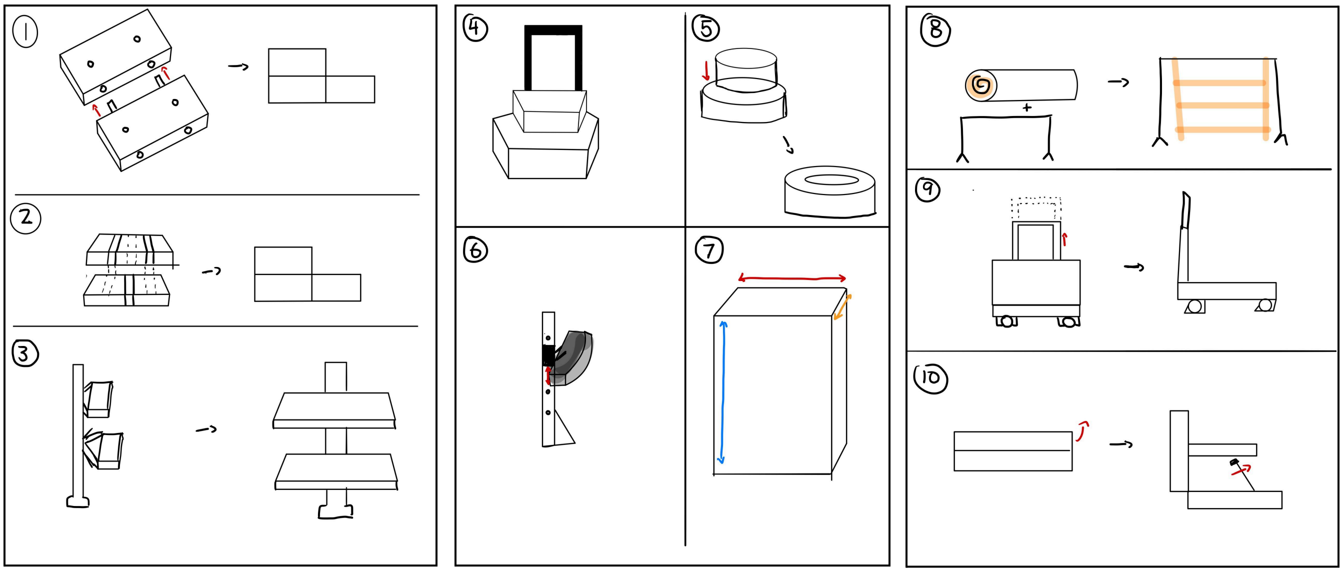
2. Sustainability:
   - Life Cycle Assessment: Conducting a comprehensive life cycle assessment (LCA) to evaluate environmental impacts across all stages of the step ladder's life, identifying areas for sustainability improvements.
   - Material Selection: Prioritizing sustainable materials with low environmental impact, considering factors such as resource depletion, pollution, and recyclability.
   - Longevity and Durability: Designing for longevity and durability to extend the product's lifespan, reduce waste, and promote sustainable consumption patterns. The LCA clearly indicated that the phases of primary concern in the product life cycle are materials and manufacturing and end-of-life. Designing with longevity in mind would increase the use phase, a phase that has little to no environmental impact.
   - Supply Chain Transparency: Promoting transparency across the supply chain by sourcing materials ethically, supporting fair labor practices, and minimizing carbon footprint in production and distribution.

3. Accessibility and Usability:
   - Universal Design Principles: Applying universal design principles to ensure the step ladder is accessible and usable for a wide range of users, regardless of age or physical ability. All primary research was conducted with a sample size that was narrow in age and current occupation, however, secondary research revealed the wide array of use cases as well as users and this was taken into consideration when redesigning a step stool
   - User-Centric Features: Incorporating user feedback and ergonomic considerations into the design to enhance usability and user experience.
   - Clear Instructions: Providing clear and user-friendly instructions for assembly, operation, and maintenance to ensure safe and effective use. Many accidents from step ladders occur due to incorrect usage and set-up: an issue that may be countered if proper labeling is applied or unnecessary.

By addressing these key areas in the design and considering potential data gaps in sustainability metrics, we aim to create a step ladder that prioritizes safety, sustainability, and user accessibility while promoting transparency and responsibility throughout the supply chain.

Ideation

The following sketches were produced before developing a prototype. A total of 60 sketches (Appendix H), 10 produced by each team member, were evaluated and the ones determined to be most in line with the problem statement and design requirements were further developed into low-fidelity prototypes.



The above sketches map onto the design requirements in the following ways:

1. Sketch 1
    a. The design meets the design requirements
        i. Step ladders and ladders should not be placed at too shallow an angle (less than 70°).
        ii. Step stool should be portable and easy to lift.
        iii. Step Stools fold & unfold safely and easily.
    b. The modular design allows the step stool to be used in a wider array of cases. A single step can be utilized for exercise and more can be attached to increase height and width.
    c. Minimal complexity allows for an easily repairable product; prologing use and mitigating need to replace whole unit
2. Sketch 2
    a. Same requirements as Sketch 1
    b. The use of straps instead of pegs turns the product into a single unit; mitigating the possibility of losing pieces and consequently shortening the life span
3. Sketch 3
    a. Same requirements as Sketch 1
    b. Minimalist design would result in a lightweight product
    c. Aesthetic design could lead to a more versatile piece -> possible shelf
4. Sketch 4
    a. Meets the following criteria

        i. Step ladders should use a wide stepping surface and allow for leaning for support
        ii. Step ladders should employ stiff materials to avoid torsion
        iii. Step ladders should not exasperate limited vision and everyday pain.
        iv. Reducing step height and providing forward lean support for fall prevention.
        v. Step ladders and ladders should not be placed at too shallow an angle (less than 70°).
        vi. Step stools should have strong stability (e.g. use a splayed base).
5. Sketch 5
    a. Same requirements as Sketch 1
    b. The all-in-one design does not require assembly, making the use more accessible
6. Sketch 6
    a. Meets requirements (ii) and (iii) from Sketch 1
    b. Adjustable height makes the stool more versatile
7. Sketch 7
    a. Meets requirement (i) from Sketch 1
    b. Design can be applied to more than one use case as the block could be moved and positioned depending on how much height is required
8. Sketch 8
    a. Meets requirements (ii) and (iii) from Sketch 1
    b. A take on a rope ladder, this design is lightweight and as easy to move as a bundle of rope
9. Sketch 9
    a. Same requirements as Sketch 4
    b. Use of wheels makes the stool easy to move, albeit not any less bulky
10. Sketch 10
    a. Same requirements as Sketch 1
    b. Folding mechanism makes the stool easy to store and does not require additional assembly

To decide which sketch would be developed into a prototype, a reevaluation of the sketches and their compliance with the engineering requirements and design specifications was conducted. It is clear that some sketches met fewer requirements and they were therefore determined insufficient for further development. After an initial round of elimination, the remaining sketches were evaluated by the team and one was selected based on research as well as enthusiasm in creating.

Prototyping I

The following prototype was created with the following criteria in mind:

1. Usability - the design is meant to have multiple functions as research revealed that the frequency at which step stools were used was at most once a month. This step stool had a simple design that was capable of taking many forms. The straps allow the blocks to

be positioned in many configurations. The step stool could be used at different heights or as a stand, shelf, display case, and step.

2. Sustainability
    a. Materials - With at most two materials used, the step stool would have less of an environmental impact than an aluminum or plastic counterpart if it were made with responsibly sourced solid wood.
    b. Assembly - The prototype consisted of blocks of the same weight and dimensions attached with straps. Blocks would be easily replaceable if damaged or misplaced. The strap attachment would equally be easily replaced if damaged. An assembly like this allows for easy repair and, consequently, an extended lifespan as the product will not need to be completely disassembled to be repaired or disposed of as a single unit.
3. Safety - the construction of the step stool consists of denser and bigger basis; this allows for a more stable design as the entire bottom surface is in contact with the ground and enough space is available for feet to get a solid footing

Further user research was conducted by conducting group interviews. All 6 prototypes (Appendix F) were evaluated and feedback was taken into account and ultimately determined further prototype development. The following details the positive and negative feedback on the above detailed prototype.

Positive	**Negative**
Use - interviewees liked the wide application of use cases the design allowed for	Potential Danger - the design required the entire product to be carried and arranged, this brought up concerns regarding weight and accessibility issues
Fun - the prototype was designed to work like a Jacob's Ladder and users enjoyed the "fun-ness" of the product	Set-up - interviewees admitted to being confused by how to set up a configuration and shared "I don't want to build a puzzle every time I want to use a step stool"

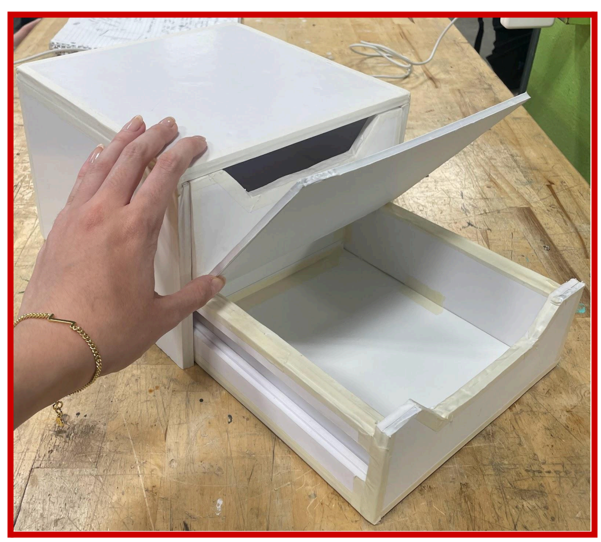
Ultimately, feedback pointed to concluding further development of this prototype. Based on commentary provided by users, the prototype created with a storage solution was further developed.

Users were enthusiastic about the potential to use the step stool as a drawer. The initial prototype was designed to have steps pulled out as a drawer; the steps could then be turned over to be used as drawers. Research revealed that students used step stools infrequently, and interviewing students with prototypes in hand further supported this claim. The potential for a step stool to be more than just a step stool was a driving force in the ideation of the final prototype. The next step to continue prototyping was to address the primary issue in the design: turning the step over while still being able to support weight on tracks.

Prototyping II

A single design was to be developed in the second prototype phase as user interviews deemed the design to be the most relevant to our audience. College students were attracted to the possibility of having a step stool that served more than one purpose. Further supported by data that pointed to the infrequent use of step stools, pursuing a multi-faceted design was the direction decided upon.

Provided that the storage solution received the most enthusiasm, the challenge in this phase of prototyping was to facilitate the process of converting a step into a drawer while simultaneously being able to carry weight in both configurations. The use of track for a sliding mechanism revealed further complications, as the tracks were not reversible and potentially incapable of holding the weight of an average person. We mitigated the need to reverse the step to a ladder by eliminating the need to rotate the entire unit. Instead, two other prototypes were created in which a piece of wood is placed above the drawer; this piece of wood serves as the step when secured above the drawer opening. If the drawer is to be accessed the piece of wood could either slide inward or be lifted when the drawer is fully open.



After further consideration and more interviews, it was determined that the sliding piece of wood was the better option, as it did not require that the drawer be opened to its full extent. Before developing the final prototype, scale and material had to be decided. With college dorm rooms in mind, the size of the prototype was modeled after existing drawer sets in Brown University dorms. The material for the prototype was determined based on the size and budget allocated for the project. Before the final prototype could be constructed, we completed a load assessment, detailed below.

Prototyping III

In the final round of prototype development, key learnings significantly influenced the approach towards manufacturing. The choice of materials, Plywood and MDF, was determined based on project size and budget considerations. Manufacturers would need to procure specific materials in bulk quantities to ensure consistency across the produced units. This may involve establishing partnerships with suppliers or sourcing materials from reliable sources to maintain quality standards.

Prior to building the prototype, a CAD model was meticulously created, followed by a thorough load assessment to ensure the product's structural integrity under the weight of an average person. The load assessment results, detailing calculations for the bottom and top step, are provided in Appendix G for reference. The CAD modeling and load assessment conducted during the prototyping phase provide crucial insights into the structural requirements of the step ladder. Manufacturers can leverage these detailed designs and calculations to create precise manufacturing plans, including cutting templates for solid wood sheets, ensuring accurate assembly and alignment during production.

The transition to high-fidelity materials from the previous foam compositions posed new challenges, particularly in the joining process. Unlike the initial stages where tape sufficed, the final prototype necessitated complex wood placement and the incorporation of materials like a nail gun and custom brackets made from sheet metal bending. A departure from a track system, common in dressers, led to the use of a router to carve tracks directly into the wood, enhancing both functionality and durability. The decision to carve tracks into the wood using a router and add finger holes for easier handling affects the production methods. Manufacturers must incorporate CNC (Computer Numerical Control) machining or routing equipment into their manufacturing facilities to replicate these precise cuts and designs across multiple units. This ensures uniformity and enhances the overall quality of the finished product.

Furthermore, the step's design saw refinement with the addition of finger holes drilled into the wood for improved handling. These design iterations not only enhance usability but also inform manufacturing processes moving forward. The shift towards more robust materials, advanced joining techniques, and precision crafting methods sets the stage for a streamlined and efficient manufacturing route that prioritizes product quality and user experience.

Design Detail

To translate the steps used to create a prototype into mass manufacturing, several key considerations and adjustments need to be made to ensure scalability, efficiency, and compliance with industry standards. Here's how each step could be adapted:[14]

1. Prototype: Usage of Brackets for Connection to Top Panel

Mass Manufacturing Approach: Instead of using brackets for connection to the top panel, wood joinery techniques can be employed in mass manufacturing. This involves utilizing methods like dovetail joints, mortise and tenon joints, or other traditional woodworking techniques to securely connect the components. Automated machinery or specialized tools can be used to ensure precision and consistency in creating these joints across multiple units. It's important to select high-quality wood and employ skilled craftsmanship to achieve durable and aesthetically pleasing connections that meet safety and regulatory standards.

2. Prototype: Router for Tracks and Filleted Edges:

Mass Manufacturing Approach: Utilize CNC (Computer Numerical Control) machining for creating tracks and filleted edges with precision and efficiency. CNC machines can replicate complex designs accurately, ensuring uniformity across multiple units.
Tooling and Maintenance: Invest in quality router bits and CNC tooling to maintain consistency and longevity in the manufacturing process. Regular maintenance and calibration of CNC machines are essential to uphold quality standards.

3. Prototype: Finger Holes for Easier Step Adjustment:

Mass Manufacturing Approach: Implement injection molding or die-casting techniques for producing step adjustment components with integrated finger holes. These methods allow for rapid production of identical parts, streamlining the assembly process.
Ergonomic Design Considerations: Ensure that the finger holes are ergonomically designed for easy grip and manipulation, considering user comfort and usability in mass-produced units.

4. Prototype: Higher Fidelity Using Wood That Can Support OSHA-Compliant Weight:

Material Selection: Opt for engineered wood or high-strength composite materials that can meet OSHA (Occupational Safety and Health Administration) weight standards while maintaining aesthetics and durability.
Quality Control and Testing: Implement rigorous quality control measures and testing protocols during mass manufacturing to ensure that each unit meets weight-bearing requirements and complies with safety standards.

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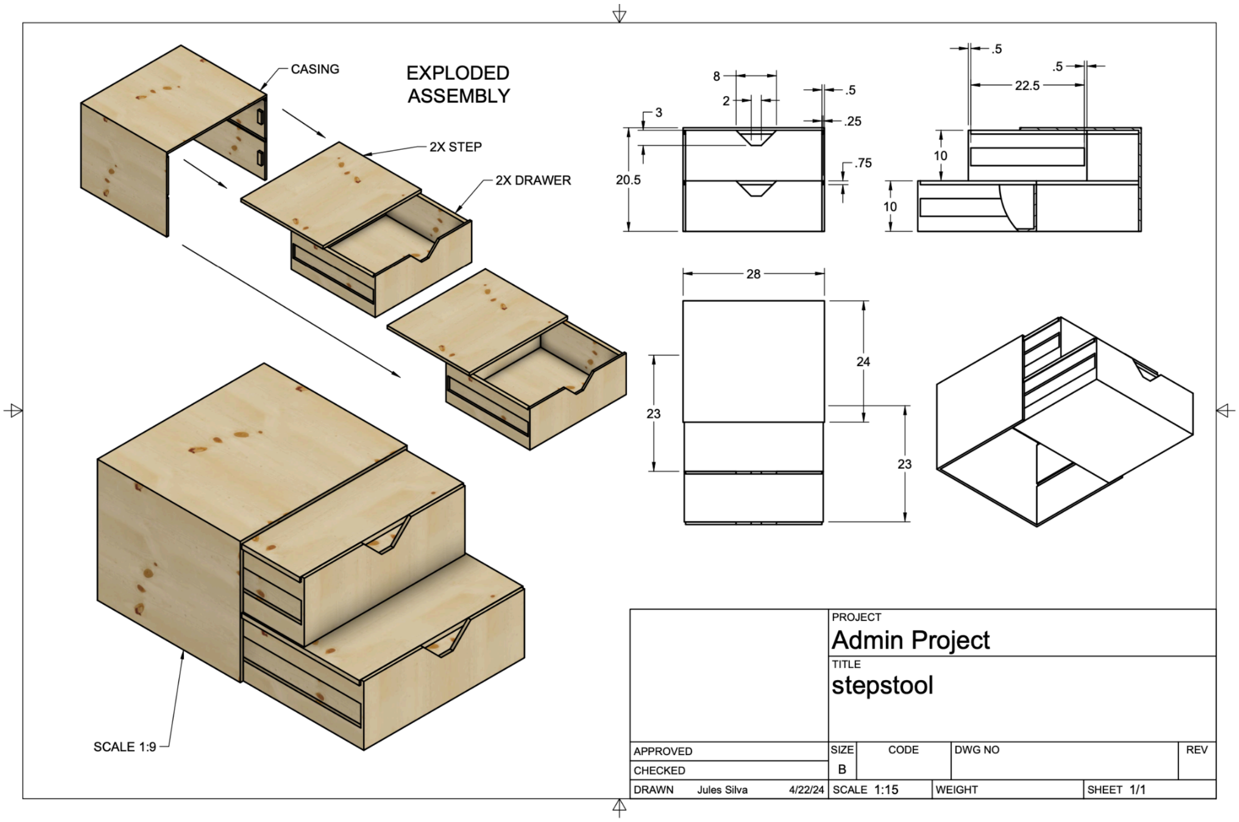
[14] Haw, J. (2024, March 29). *From prototype to production: Scaling for mass production*. OpenBOM. https://www.openbom.com/blog/from-prototype-to-production-scaling-for-mass-manufacturing

Additionally, in mass manufacturing, considerations such as supply chain management, production scalability, cost-effectiveness, and regulatory compliance become paramount. Collaborating with suppliers, conducting thorough testing and validation, optimizing production workflows, and adhering to industry standards are integral steps in successfully transitioning from prototype development to mass manufacturing.

The drawing below illustrates what a final product would look like. The design does not stray from the final prototype, changes would include material.



Future Work

As we look ahead to the future of step ladder design and manufacturing, several key opportunities and advancements come into focus. These future directions not only build upon the foundation laid by our current research and prototype development but also pave the way for innovation and market expansion.

1. Built-in Furniture Opportunities: Extending Past the Dorm

One promising avenue for future exploration lies in the integration of built-in furniture functionalities into step ladder designs. While our initial focus has been on catering to college dormitory settings, there is immense potential to extend these designs to various other environments such as homes, offices, and commercial spaces. By incorporating features like storage compartments, foldable desks, or seating options, step ladders can transform into multifunctional pieces of furniture that enhance space utilization and convenience. This expansion beyond the dormitory market opens up new opportunities for product diversification and market penetration.

2. Current Customer: Colleges Purchasing in Bulk

Our current customer base primarily comprises colleges and educational institutions purchasing step ladders in bulk quantities. This trend is expected to continue, presenting an opportunity for establishing long-term partnerships with these institutions. Collaborative efforts in product customization, volume discounts, and tailored solutions can strengthen our position as a preferred designer, fostering loyalty and repeat business. Additionally, exploring avenues for expanding our customer base to include other sectors such as hospitality, healthcare, and retail can further diversify our market reach and revenue streams.

3. Mass Manufacturing Using CNC Machining[15]

Transitioning from handcrafted prototypes to mass production necessitates the adoption of advanced manufacturing techniques. CNC (Computer Numerical Control) machining emerges as a highly efficient and precise method for mass manufacturing step ladders. Compared to traditional hand routing and chiseling, CNC machining offers greater scalability, consistency, and automation in producing intricate joinery, cuts, and profiles. This technological advancement not only streamlines the manufacturing process but also enhances product quality, reduces production time, and enables customization at scale.

4. Joinery Rather Than Brackets for the Lid

In line with our commitment to craftsmanship and durability, future step ladder designs will prioritize joinery techniques over brackets for lid attachment. Utilizing methods such as dovetail joints, mortise and tenon joints, or other traditional woodworking techniques ensures robust and visually appealing connections.[16] These joinery methods not only enhance the structural integrity of the step ladder but also contribute to its aesthetic appeal and premium feel. By emphasizing craftsmanship and quality joinery, we differentiate our products in the market and cater to discerning customers seeking durable and well-crafted solutions.

In conclusion, the future of step ladder design and manufacturing is brimming with opportunities for innovation, market expansion, and technological advancements. By capitalizing on built-in furniture concepts, catering to bulk purchasers, embracing CNC machining, and prioritizing quality joinery, we position ourselves for sustained growth, customer satisfaction, and competitiveness in the evolving market landscape.

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[15] Velling, A. (2024, January 26). *CNC milling - a complete guide to understand the process*. Fractory. https://fractory.com/cnc-milling/
[16] Dixon, J. (2024, March 3). *Dovetail joints vs mortise and tenon when to use which*. Wood Working Squad. https://woodworkingsquad.com/dovetail-joints-vs-mortise-and-tenon-when-to-use-which/

Appendix

A.

Interview Questions – Step Ladder/Foot Stool

1. Do you own a step ladder?
    a. How often do you use it? What do you use it for?
2. Define the object. Is there a difference between a step ladder and a step stool?
3. What kind of person do you picture using a step ladder? Does this affect your choice to have/not have a step ladder?
4. Where would you/ do you store a step ladder?
5. What are some pain points of using a step ladder?
6. What do you associate a step ladder with?
7. Do you have any fond memories which involve a step ladder?
8. Have you ever witnessed or experienced a ladder incident or mishap?
9. Do you remember a time when you weren't able to reach something and you needed assistance?

B.

Stepladder Interview:

1 CIT

0. 20, student
1. NO, yes (at home)
   a. once a month, smoke alarm replacement
   mom uses to grab stuff
2. "Anywhere I can step to reach a higher place?"
3. shorter people - don't need bc tall, but always nice to have one
4. closet / garage
5. Not stable, too lazy to go grab it
6. household objects
7. NO - changing a lightbulb as a kid
8. NO

2 CIT

0. 20, 21
1. NO, at home - used once in his life to reach a high shelf
2. platform to reach higher
3. Anyone, shorter ppl maybe
   a. NO, but maybe if I was shorter & couldn't reach all the shelves in house
4. garage
5. scared of heights, wobbly, hard to unfold / fold
6. Handiwork
7. NO
8. once on the internet - ppl falling off

sci li

3

0. 21, student

1. at home
   > change security cameras whenever they run out of battery

2. small ladder w/ steps instead of rungs

3. people who come and work on your house
   > does not affect choice to have /not

4. in garage

5. scared to fall off

6.

7. locked out, used to get back in the house

8. NO

9. high shelf

sci-li

4

0. 20, student

1. don't have, haven't used
   > need to reach high and can't climb on other stuff

2. portable smaller ladder that helps ppl reach things they otherwise wouldn't be able to.
   - step stool is one platform - step ladder has multiple steps

3. > someone who is shorter would use a step ladder > step stool, thinks of the gym "wouldn't have the need to use one even if I have one"

4. closet or empty wall

5. hard to fold / move around / is heavy, lack of stability, if the metal is sharp

6. grandma getting something off top of spice-rack
   - "kitchen-coded"

7. NO

8. Changing smoke alarm in unusually high ceiling (on a chair) - hurt shoulder supporting himself on wall.

9. Nothing specific comes to mind, but probably

sci-li

5

0. 20, student

1. At home and in off-campus house
   > use once every 2 months, changing light bulbs and smoke detector batteries
2. equipment w/ more than 1 rung that can bear weight
   > step stool can be same thing, but just one rung, and can be used as an alternative surface. step ladder is at least 2 rungs, step stool can be more than 1 though
3. Anyone, step stool is usually kids for sink, step ladder usually for home repair / improvement project
   step stool I use as another surface in addition to counter space for food, bowls, whatnot
   > I'd want to be prepared - have both

4. Kitchen step stool folds, so next to refrigerator or wherever nearby, convenient space
   step ladder in garage / shed / closet / basement, where tool box & home improvement equipment is stored
5. prone to breaking (cheap ones) — step stool
   step ladder is bulky / clunky & hard to fold-unfold,
   & if step ladder doesn't feel like it securely locks in place when open (it will rattle when stepped on - doesn't like)
6. universal increase height - step stool
   repair - step ladder
7. sister had monogramed step stool.
   step stool as table for extra space during dinner
   got hit in shin using metal step ladder. is loud.
8. Yes - sister falling backwards off it

9. Yes - couldn't reach smoke alarm battery and had to have someone else

★ seems important to make distinction between step stool vs. step ladder in interviews

6

0. 22, student

1. at home, once every 6 mo.
   > if ever need to get stuff out of cabinets (am short - 4'9)

2. boards you use to raise yourself higher to grab something out of reach
   no difference

3. "someone like myself, who's short"
   does not affect my choice

4. garage

5. taking it out of garage - can be heavy, cumbersome to carry

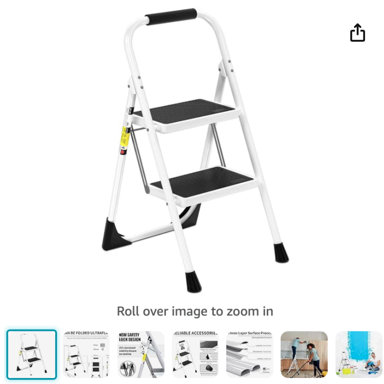
6. doing things around the house, daily activities

7. No

8. No

9. yes, many times while in dorms I have to ask others. Using 0 stacked laundry machines, had to put all clothes in top drier (only one available) had to ask roomate

C.



Roll over image to zoom in

Step Ladder EFFIELER 2 Step Stool Ergonomic Folding Step Stool with Wide Anti-Slip Pedal 430 lbs Sturdy Step Stool for Adults Multi-Use for Household, Kitchen, Office (Matte White)

Visit the EFFIELER Store

4.7 ★★★★☆ 2,993 ratings

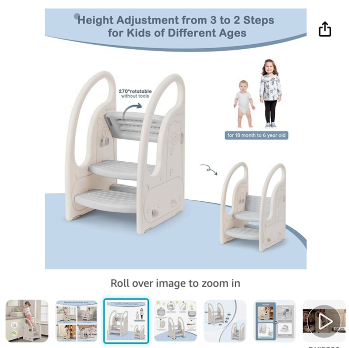
Amazon's Choice in Kids' Step Stools by EFFIELER

1K+ bought in past month

Deal

-15% $30.59

1



Roll over image to zoom in

Toddler 3 Step Stool Onasti Kids Standing Tower for Toddlers Plastic Learning Helper Stool for Kitchen Counter Bathroom Sink Toilet Potty Training with Handles and Non-Slip Pads-Grey White

Visit the Onasti Store

4.7 ★★★★☆ 584 ratings

Amazon's Choice in Nursery Step Stools by Onasti

500+ bought in past month

-7% $75.99

2

Roll over image to zoom in

Hasegawa Ladders Lucano Step Ladder, 2-Step Orange

Visit the Hasegawa Store

5.0 ★★★★★ 2 ratings

$206.40

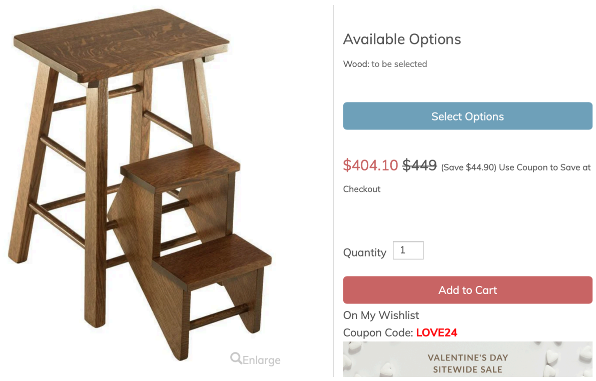
FREE Returns

Get $50 off instantly: Pay $156.40 upon approval for Amazon Visa.

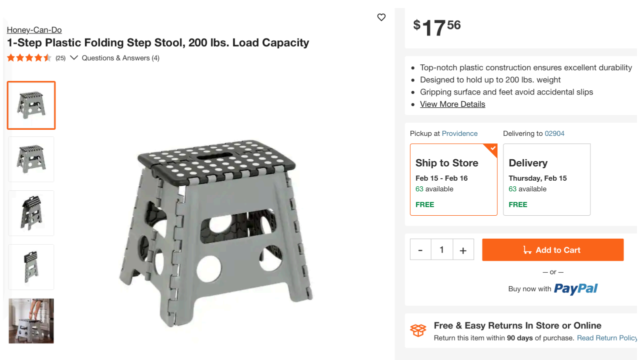
Color: **Orange**

Material	Aluminum
Brand	Hasegawa
Product Dimensions	6"W x 24.5"H
Color	Orange
Special Feature	stand on its own interior good design award, supreme ladder

3


Available Options
Wood: to be selected
Select Options
$404.10 $449 (Save $44.90) Use Coupon to Save at Checkout
Quantity 1
Add to Cart
On My Wishlist
Coupon Code: LOVE24
VALENTINE'S DAY SITEWIDE SALE
Enlarge

4


Honey-Can-Do
1-Step Plastic Folding Step Stool, 200 lbs. Load Capacity
Questions & Answers (4)
$17 56
Top-notch plastic construction ensures excellent durability
Designed to hold up to 200 lbs. weight
Gripping surface and feet avoid accidental slips
View More Details
Pickup at Providence
Delivering to 02904
Ship to Store
Feb 15 - Feb 16
63 available
FREE
Delivery
Thursday, Feb 15
63 available
FREE
Add to Cart
– or –
Buy now with PayPal
Free & Easy Returns In Store or Online
Return this item within 90 days of purchase. Read Return Policy

5

D.

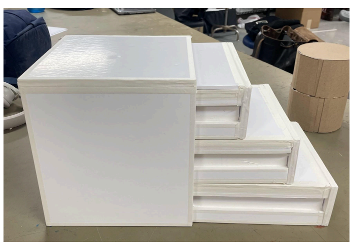
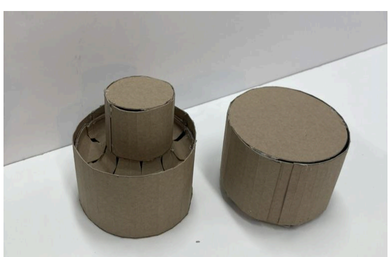
	Lawful	Neutral	Chaotic
Good	Lawful Good	Neutral Good	Chaotic Good
Neutral	Lawful Neutral	True Neutral	Chaotic Neutral
Evil	Lawful Evil	Neutral Evil	Chaotic Evil

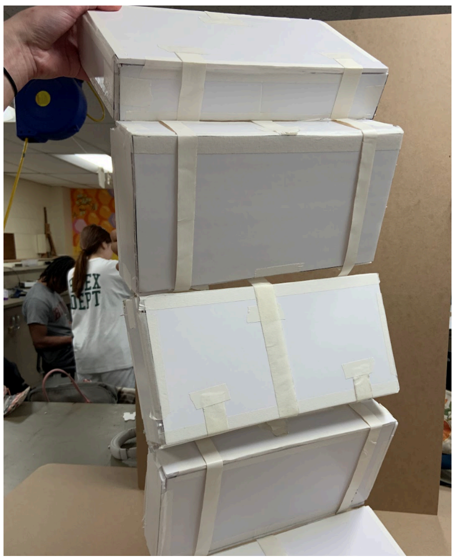
E..
(1) small what i would think when asked about a step ladder (lawful neutral)
Not kids, adults - have one of these at my house ubiquitous one
(2) looks likes its meant for kids, looks safer, psychology of kids on the picture (lawful good)
(3) more expensive - “it’s all minimalist, people love that shit” (Chaotic Neutral) why are the steps so small?
(4) just as expensive “but this one’s cute” I would put this one in my living room (chaotic good) - small steps
(5) looks like its $16, does what its supposed to do (neutral good)
(1)maybe not that sturdy, but maybe not; like the look “streamlined” (true neutral)
(1)good rating, amazon’s choice (neutral evil)
(2) looks like its for children “the curve, no sharp points” (lawful neutral)
(2) rotates to become smaller, “it's got handlebars, makes it more accessible” (neutral evil)

(3) probably easy to store (chaotic evil)
(3) I wouldn't buy that' incline looks very steep, too narrow, $200 (chaotic evil)
(4) "I'm intrigued by this one" looks sturdy - contacts with the ground, materials has a say (Chaotic good) thinking big and bulky
(4) agree with everything that was said (lawful good) someone could have made it "true craftsmanship"
(5) hard to be objective, has used one, grips could be helpful, a little worried about it being flimsy but not to much (Neutral evil) doesn't excite me but for dorm first or last
(5) Roommate has this one, handle makes it transportable (Lawful good)
(1) Would have to be for a short shelf, very safe and sturdy(lawful good) standard
(2) play one, train to teach to use a play ladder, only two steps visual look is playful (lawful evil)
(3) looks like a chair, would not use personally, very thin not study (chaotic evil)
(4) kind of cray, never seen something like it, wonder if it can serve as a table, sturdy because 4 stands, looks like it goes with different aesthetics (Chaotic good)
(5) cheap x2, would trust it, hinges look sturdy (lawful neutral)

Interior design
Cost, no more than 70
Sturdiness
(1) fear for my life, second one is way to tall (lawful neutral)
(1) "where are we in a hospital, get me out of here" (lawful evil)
(2) for a child, don't like it (chaotic neutral)
(2) gonna break, no thank you, looks hollow (chaotic evil)
(3)(chaotic evil)
(3)what in the architecture, fuck no (chaotic evil)
(4)this i like, but the price lawful neutral
(4)I don't know, i don't think i will use it just look at it (chaotic good)
(5)I have one of those, something about it pisses me off, falls over just put it under the sink(neutral evil
(5)(chaotic neutral)
(1) i like that one it looks sturdy made out of medal, used it at work (lawful good)
(2) i would break it, get flattened by me, kids learning to go up stairs (neutral good)
(3) looks like id break it, color looks ably but if they wanted an aesthetic chair they would pick it (chaotic neutral)
(4) no, don't want to do step ups that price, no (chaotic evil)
(5) pinch my skin, wobbly, reliable (true neutral)

F.

Prototype	Design Requirements Met
Jules	Stability ensured through denser and bigger basis and design; Modularity ensured through assemble design; Sustainability ensured through the possibility for wooden material as the base
 	Stability ensured through denser and bigger basis and design; Modularity ensured through three different levels; Multi-functionality ensured through prototype’s conversion into drawers when not needed anymore or for a long period of time; Sustainability ensured through the possibility for wooden material as the base
 	Stability ensured through denser and bigger basis and design; Multi-functionality ensured through prototype’s function as an ottoman or chair; Portability; Sustainability ensured through the possibility for wooden material as the base

Prototype	**Design Requirements Met**
 	Stability ensured through denser and bigger basis and design; Modularity ensured through a buildable, stackable design; Multi-functionality; Portability; Sustainability ensured through the possibility for wooden material as the base
	Stability ensured through denser and bigger basis and design; Modularity ensured through [...]; Sustainability ensured through the possibility for wooden material as the base

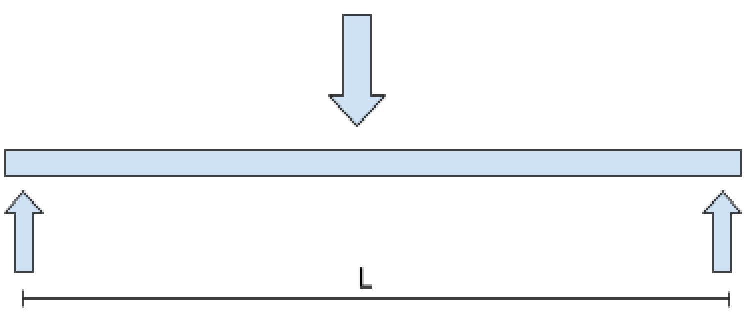
Prototype	Design Requirements Met
 	Stability ensured through denser and bigger basis and design; Modularity ensured through its buildable, stackable structure leveraging leg extensions and latches; Multi-functionality ensured through prototype's function as a table or a piece for extra space; Sustainability ensured through the possibility for wooden material as the base

G.

Beam bending analysis with supports on both ends and a center load

Existing Specs:

- 24" x 28" x 0.75" wood panel
- OSHA standard of 250 lb load at center (From Design Requirements table)
- Young's Modulus of Plywood 7 GPa (conservative estimate)



Force at center

$$F = 114\, kg\ x\ 9.81\ \frac{m}{s^2} = 1117.2\ N$$

Area moment of inertia

$$I = \frac{bh^3}{12} = \frac{(609.6\, mm)(19.05 mm)^3}{12} = 351195\ mm^4$$

Beam Displacement

$$\delta = \frac{FL^3}{48\, EI} = 3.41\ \ mm$$

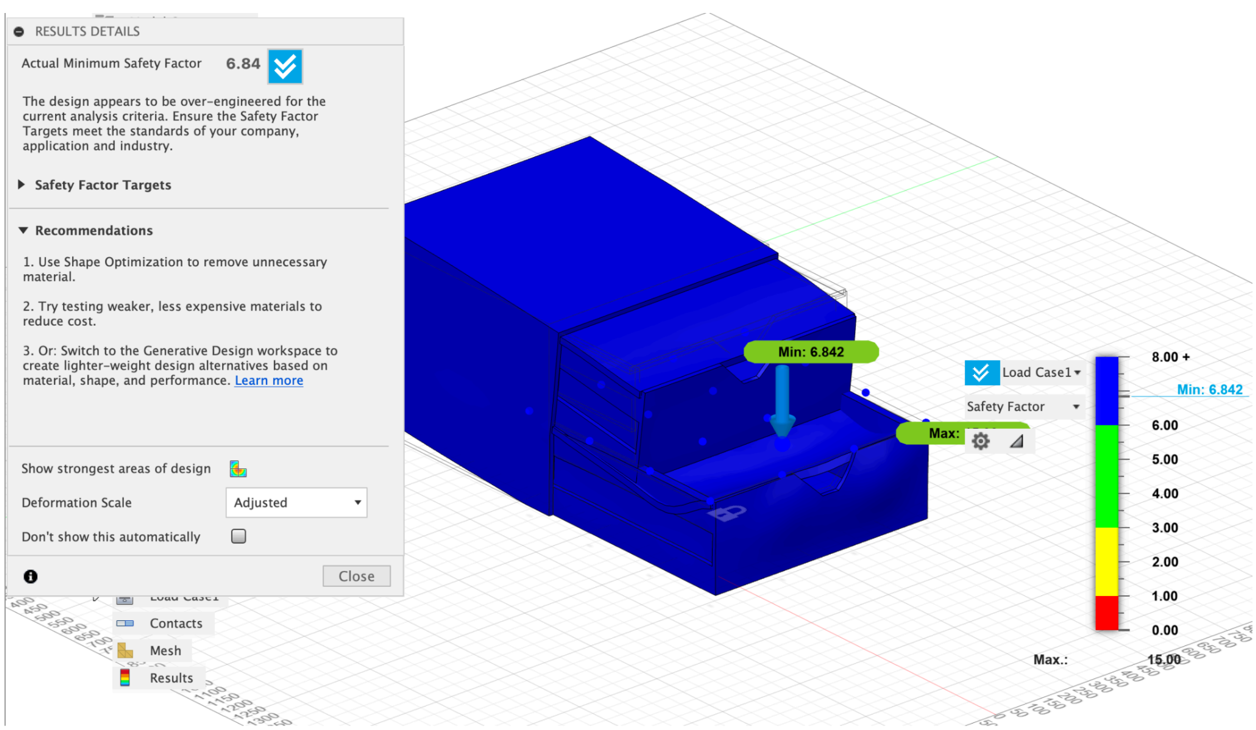
$$\sigma = \frac{y_{max}FL}{4I} = 5.39\ Mpa$$

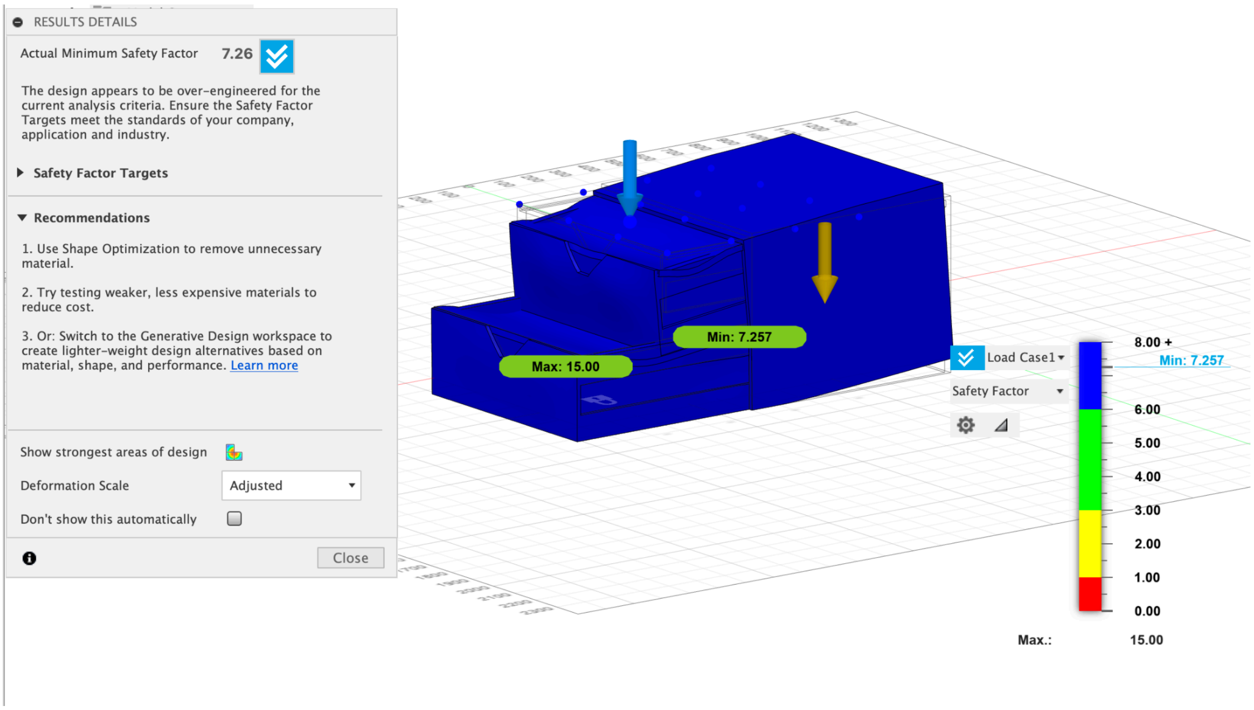
Tensile strength of Plywood in 17.6-34.5 Mpa range

CAD estimations done with MPA fiberboard used as material (Plywood not an option)

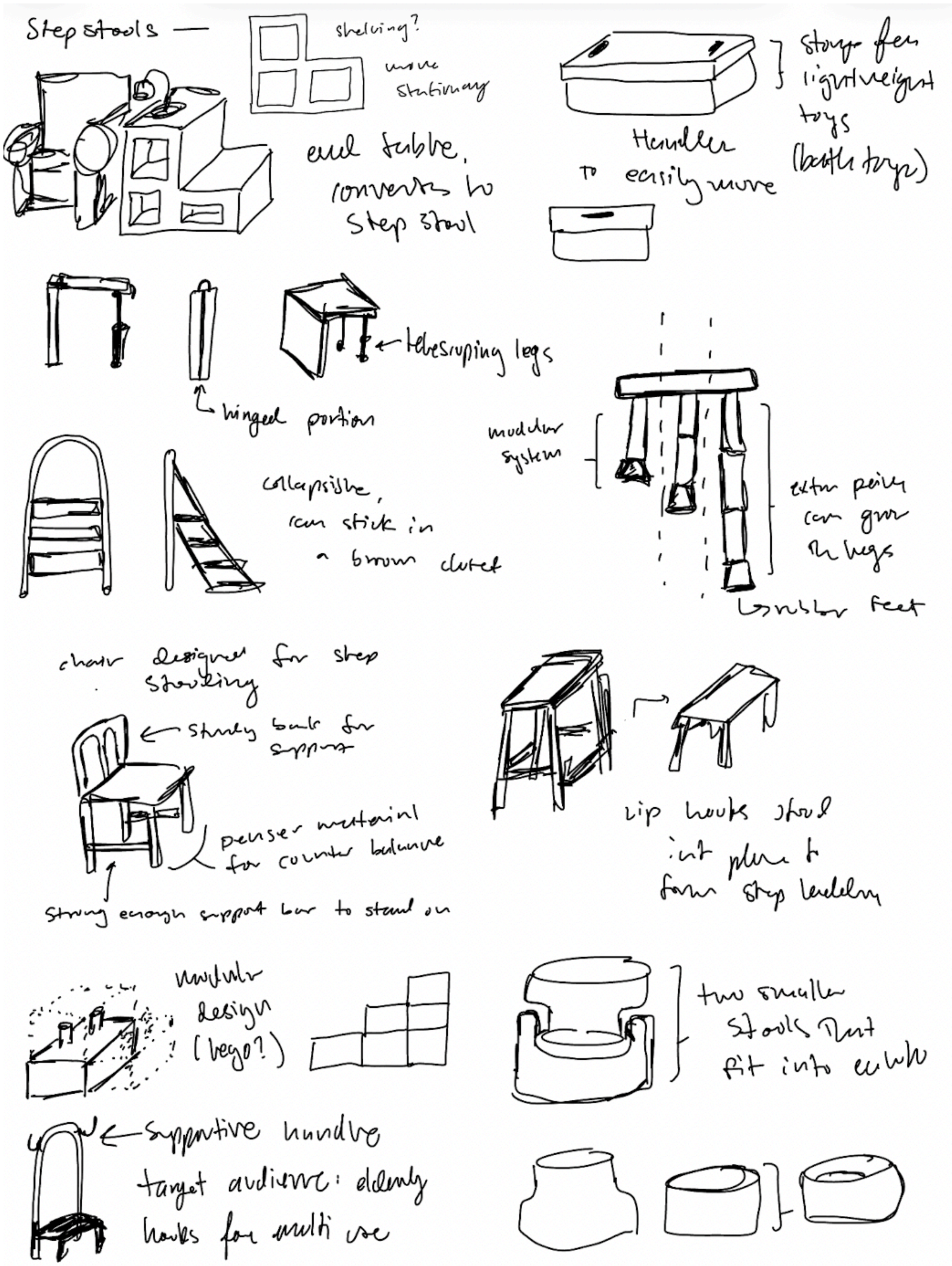
- Young's modulus of 4 Gpa

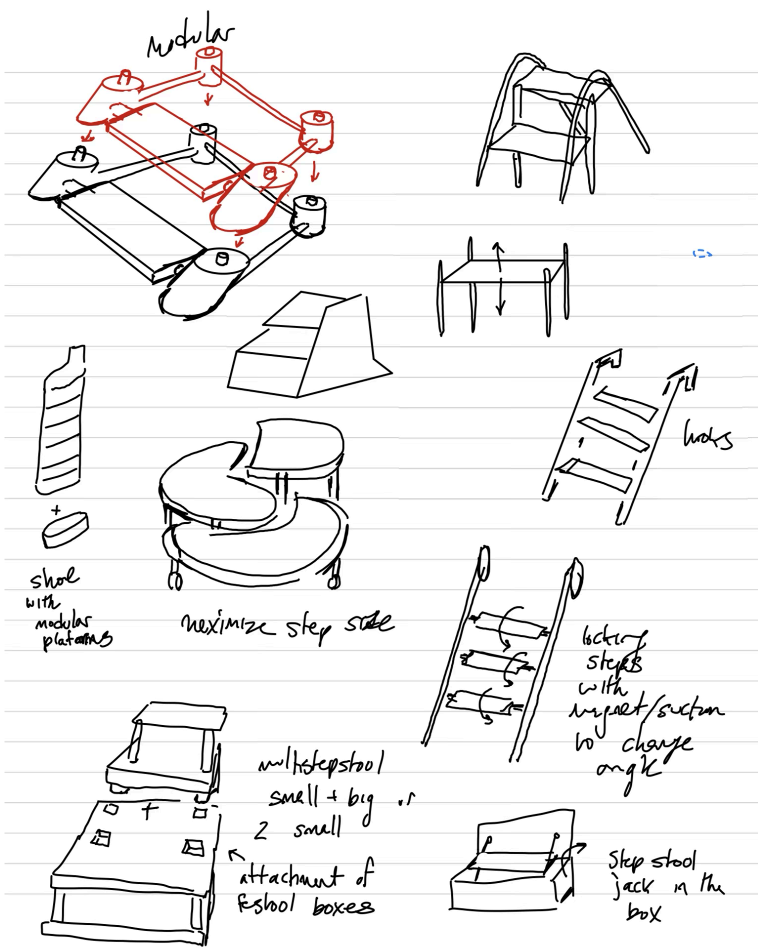
Mpa = N/m^2 * 10^-6

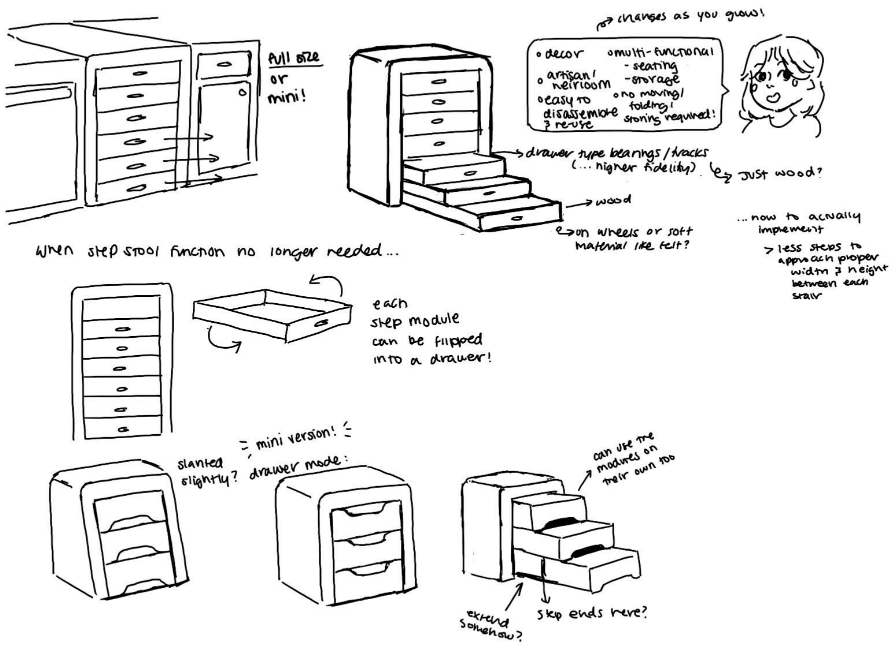


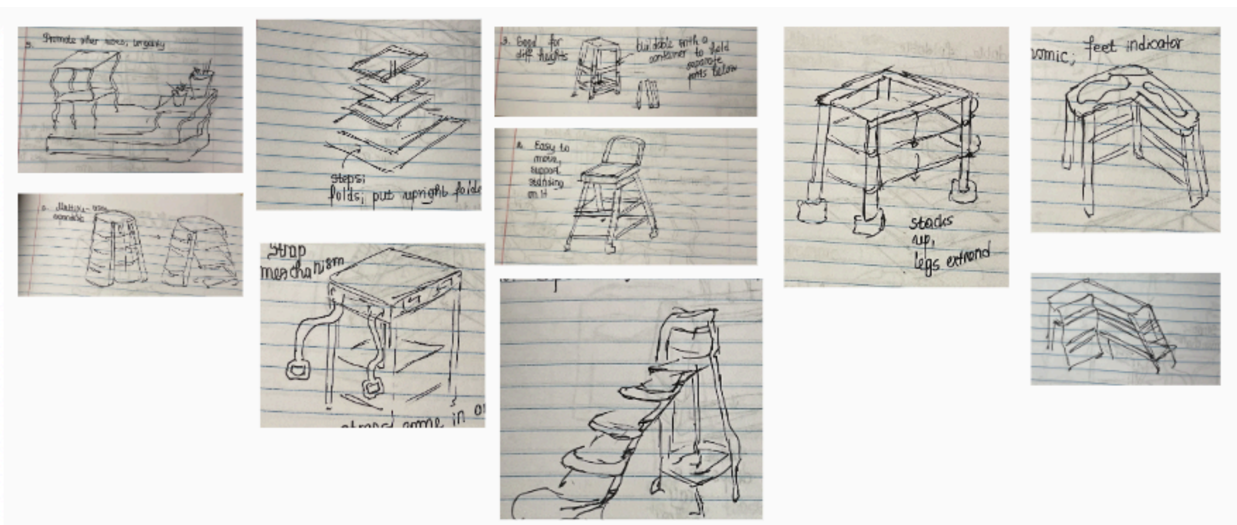

RESULTS DETAILS
Actual Minimum Safety Factor 7.26
The design appears to be over-engineered for the current analysis criteria. Ensure the Safety Factor Targets meet the standards of your company, application and industry.
Safety Factor Targets
Recommendations
1. Use Shape Optimization to remove unnecessary material.
2. Try testing weaker, less expensive materials to reduce cost.
3. Or: Switch to the Generative Design workspace to create lighter-weight design alternatives based on material, shape, and performance. Learn more
Show strongest areas of design
Deformation Scale
Adjusted
Don't show this automatically
Close
Min: 7.257
Max: 15.00
Load Case1
Safety Factor
8.00 +
Min: 7.257
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Max.:
15.00

H.


Step stools —
shelving?
more stationary
end table, converts to step stool
storage for lightweight toys (bath toys)
Handles to easily move
telescoping legs
hinged portion
modular system
extra pieces can grow the legs
rubber feet
collapsible, can stick in a broom closet
chair designed for step stooling
sturdy back for support
denser material for counter balance
strong enough support bar to stand on
lip hooks stool into place to form step ladder
modular design (lego?)
two smaller stools that fit into each
supportive handle
target audience: elderly
hooks for multi use


Modular
locks
shoe with modular platforms
maximize step size
locking steps with magnet/suction to change angle
multistepstool
small + big or
2 small
attachment of stool boxes
Step stool jack in the box


full size
or
mini!
changes as you grow!
decor
artisan/
heirloom
easy to
disassemble
& reuse
multi-functional
- seating
- storage
no moving/
folding/
storing required!
drawer type bearings/tracks
(... higher fidelity)
just wood?
wood
on wheels or soft
material like felt?
... how to actually
implement
> less steps to
approach proper
width & height
between each
stair
when step stool function no longer needed...
each
step module
can be flipped
into a drawer!
mini version!
slanted
slightly?
drawer mode:
can use the
modules on
their own too
extend
somehow?
step ends here?


feet indicator
steps;
folds; put upright folds
Strap
mechanism
stacks
up,
legs extend