User Interface and Data Visualization for Environmental Assessment

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Abstract

Life cycle assessment (LCA) is a powerful method used to quantify the environmental impacts of a product or service across stages of its life cycle. It can serve to guide the product development process or establish a baseline for customers to make more informed decisions about the products they buy. While software solutions to automate aspects of the LCA process exist, they either have high learning curves stemming from outdated and complex interfaces or suffer from overly simplistic data visualization. The former requires expert knowledge to navigate, while the latter offers no additional direction in the decision making process beyond viewing environmental impacts. As such, there is potential for improvement in these areas to foster wider adoption of LCA software, particularly by product designers and engineers who may have less expertise in environmental assessment.

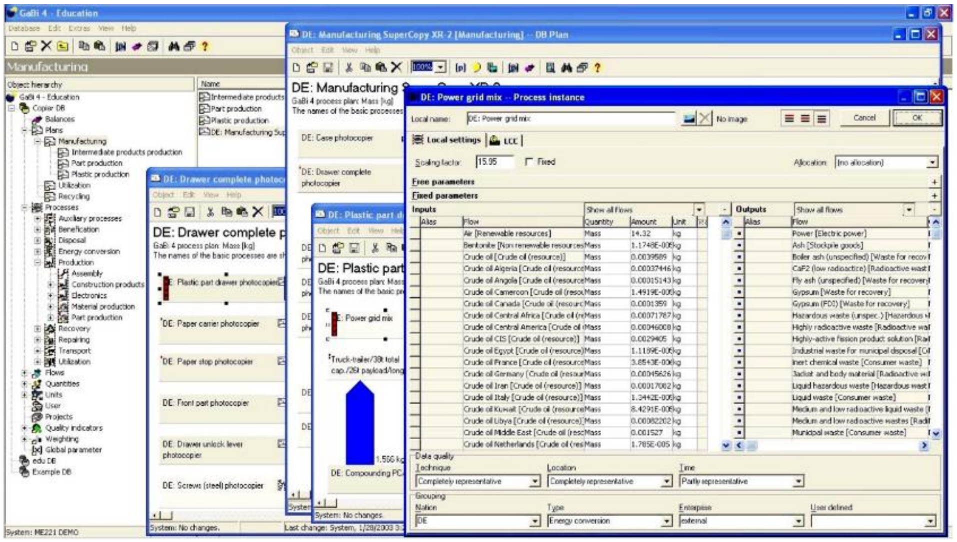
The first half of this paper will focus on technical contributions towards achieving this goal starting with the shared task of designing prototypes and user testing in order to understand our target user's workflow process. This is followed by details on implementation tasks, which were split into model building and data visualization components. My teammate, Jonya Chen, discusses model building implementation and challenges in her paper, while this paper covers data visualization and back-end implementation.

The second half of this paper will then seek to place our LCA application in a broader context by evaluating the ecosystem in which the software would be employed. It will explore potential driving forces for the adoption of such a software, especially by small and medium enterprises. The packaging industry will also be explored as a case study example for positioning of LCA software in a particular industry.

Part I: Technical Contributions

1 Motivation for life cycle assessment software improvement

Being able to assess the environmental impact of a product promotes sustainable design. One such method to accomplish this is life cycle assessment (LCA) in which a product or service's "environmental burdens… [are] assessed, back to the raw materials and down to waste removal" (Klöpffer, 1997, p. 223). As such, LCA aids in the ability to reduce pollution and conserve resources to improve product sustainability (Rebitzer et al., 2014). However, current software aiding in general life cycle assessment are on the extremes of the learning curve and data visualization spectrum. Powerful tools, such as Gabi (Thinkstep, 1991), allow for users to have high control and customization in their analysis but are "complicated to use and not user-friendly" (Ren & Su, 2013, p. 48) Whereas simplified tools, such as Sustainable Minds (Sustainable Minds, 2008), allow ease in modeling systems but lack in detailed qualification of the results to improve assessments (Ren & Su, 2013). This can be seen in Figures 1 and 2, respectively. These extremes make it slow and difficult to obtain meaningful interpretation of results for the non-expert.



Local name: DE: Power grid mix

Scaling factor: 15.95 ☐ Fixed

Allocation: [no allocation]

Inputs: Show all flows

Alias	Flow	Quantity	Amount	Unit
	Air [Renewable resources]	Mass	14.32	kg
	Bentonite [Non renewable resources	Mass	1.1748E-005	kg
	Crude oil [Crude oil (resource)]	Mass	0.0039589	kg
	Crude oil Algeria [Crude oil (resource	Mass	0.00037446	kg
	Crude oil Angola [Crude oil (resource	Mass	0.00015143	kg
	Crude oil Cameroon [Crude oil (resou	Mass	1.4919E-005	kg
	Crude oil Canada [Crude oil (resourc	Mass	0.0001359	kg
	Crude oil Central Africa [Crude oil (re	Mass	0.00071787	kg
	Crude oil Central America [Crude oil (	Mass	0.00046008	kg
	Crude oil CIS [Crude oil (resource)]	Mass	0.0029405	kg
	Crude oil Egypt [Crude oil (resource)	Mass	1.1189E-005	kg
	Crude oil France [Crude oil (resource	Mass	3.8543E-006	kg
	Crude oil Germany [Crude oil (resour	Mass	0.00045626	kg
	Crude oil Iran [Crude oil (resource)]	Mass	0.00017082	kg
	Crude oil Italy [Crude oil (resource)]	Mass	1.3442E-005	kg
	Crude oil Kuwait [Crude oil (resource	Mass	8.4291E-005	kg
	Crude oil Libya [Crude oil (resource)]	Mass	0.00082202	kg
	Crude oil Middle East [Crude oil (resc	Mass	0.001527	kg
	Crude oil Netherlands [Crude oil (res	Mass	1.785E-005	kg

Outputs: Show all flows

Alias	Flow
	Power [Electric power]
	Ash [Stockpile goods]
	Boiler ash (unspecified) [Waste for recov
	CaF2 (low radioactice) [Radioactive wast
	Fly ash (unspecified) [Waste for recovery
	Gypsum [Waste for recovery]
	Gypsum (FDI) [Waste for recovery]
	Hazardous waste (unspec.) [Hazardous w
	Highly radioactive waste [Radioactive wa
	Highly-active fission product solution [Ra
	Industrial waste for municipal disposal [C
	Inert chemical waste [Consumer waste]
	Jacket and body material [Radioactive w
	Liquid hazardous waste [Hazardous wast
	Liquid waste [Consumer waste]
	Medium and low radioactive liquid waste [
	Medium and low radioactive wastes [Radi
	Municipal waste [Consumer waste]

Data quality

Technique: Completely representative

Location: Completely representative

Time: Partly representative

Grouping

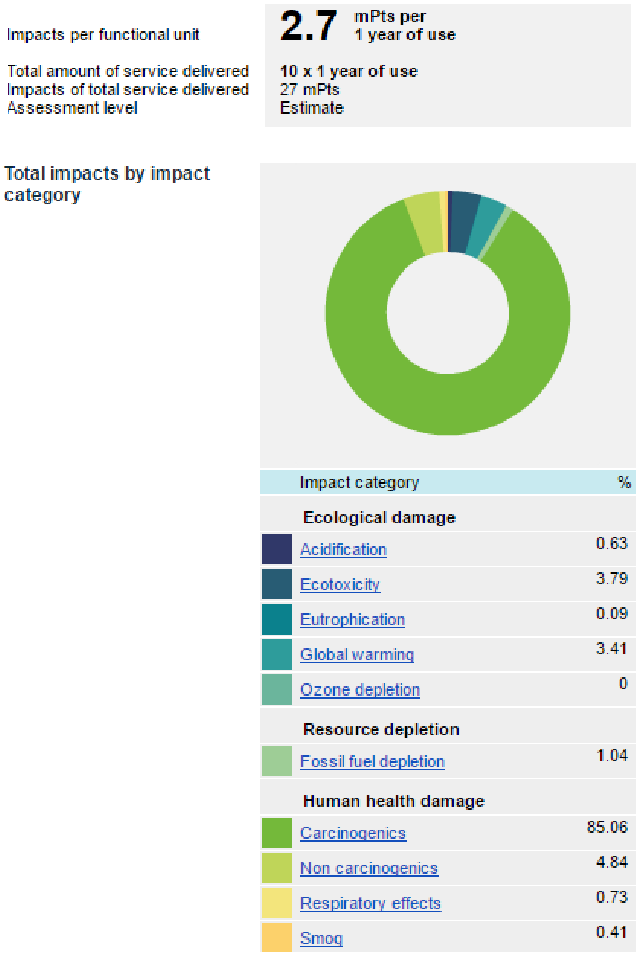
Nation: DE

Type: Energy conversion

Enterprise: external

User defined:

Figure 1. Multi-screened, complex user interface for modeling environmental impacts from GaBi4.



Impacts per functional unit: 2.7 mPts per 1 year of use

Total amount of service delivered: 10 x 1 year of use

Impacts of total service delivered: 27 mPts

Assessment level: Estimate

Total impacts by impact category

	Impact category	%
	Ecological damage	
🟦	Acidification	0.63
🟦	Ecotoxicity	3.79
🟦	Eutrophication	0.09
🟦	Global warming	3.41
🟩	Ozone depletion	0
	Resource depletion	
🟩	Fossil fuel depletion	1.04
	Human health damage	
🟩	Carcinogenics	85.06
🟩	Non carcinogenics	4.84
🟨	Respiratory effects	0.73
🟧	Smog	0.41

Figure 2. Single endpoint impact score decomposed into midpoint scores from Sustainable Minds doesn't provide users with additional information on certainty/quality of reported scores.

In an effort to expand the user base for LCA software beyond the expert LCA practitioner to product designers and engineers, we propose that an improved workflow involving uncertainty analysis will save time in collecting product information, ease the learning curve of running LCA, and provide more informative results. The improved workflow relies on two major components: facilitating model building and displaying uncertainties associated with calculated environmental impacts. User testing was performed for various model building and data visualization design prototypes followed by an implementation phase of concepts and insights gleaned from user testing.

2 Understanding the user through iterative design, prototyping, and user testing

One major goal of our project is to increase LCA adoption amongst product designers and engineers. As such, understanding how to better facilitate in the process of conducting LCA was of most importance. The design process consisted of iterations of rapid prototyping and user testing to not only come to an understanding of our target user but to also ensure that the translation of that understanding to a software functionality was accurate. The user testers were selected from a pool of Master's of Engineering candidates with experience in product design and/or mechanical engineering. It is important to note that this mostly homogenous pool of similarly aged students with limited industry experience may have introduced bias in our user testing. Insights can be further improved by broadening the pool to include individuals with more industry experience or from other engineering disciplines.

The prototyping and user testing phase was a joint responsibility that involved brainstorming various prototypes, splitting up and conducting user tests, and discussing results as a preface to the next round of iterations as can be seen in Figure 3. This was done in two phases – one for prototyping model building and the other for data visualization.

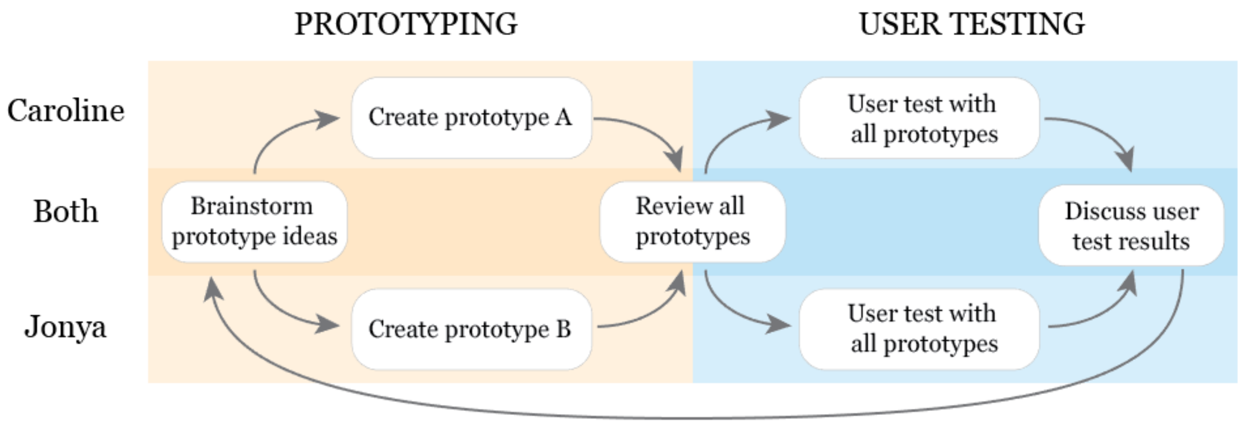


Figure 3. Individual responsibilities in the design cycle phase.

2.1 Model building prototypes helped identify user workflow

The designs started off as low-fidelity paper prototypes, in which we would simulate the computer response to interactions during user testing. The use of low-fidelity prototyping at the early stages allowed for many rough ideas to be explored due to its fast turnaround (Wong, 1992). Users were given a bill of materials for a fridge as well as information gathered about its transportation, energy consumption, and product end of life (see Appendix A.1) and asked to navigate inputting the information in the multiple prototypes.

The initial prototypes, examples of which can be seen in Appendix A.2-5, explored a variety of workflows as well as representations for library and model components. User testing questions explored how to best support intuitive workflow. These included how users would add components to a model as well as how to guide users through the process of conducting life cycle assessment. The major differences tested were: 1) having a constant library of materials/processes or life cycle tabs leading to areas where specific components could be added; 2) associating processes in the same step as selecting a material (one-shot) or after materials are added to the model (one-by-one); and 3) model components in a listed format or as draggable objects on a workspace.

From the first user test, there was a general consensus that the tabs provided structure in understanding general steps of running life cycle assessment but users preferred the flexibility of an open library. Users commented that direct association of components in the same step could be complex when the user desires to link many components and would likely require many mouse clicks. Rather, they preferred association via direct manipulation where components could be dragged together to link. Despite this, the list views of the model fared better than the workspace layout due to concerns of display complexity with models consisting of a large number of components.

With a general sense of the users' workflow, the second and third design iterations sought to expand upon the differences between the workspace and list view (Figures 4a-c), to explore various prototypes for streamlining component associations (Figures 5a-b), and to introduce concepts for grouping/creating subassemblies (Figures 6a-b). A major disadvantage of the earlier paper prototypes was that the simulated interactions on paper are not reflective of how a user may actually interact with a system. As Uceta et al. (1998) suggest, PowerPoint™ can be an effective means of adding interactivity by hyperlinking screens together to emulate an interaction. The remainder of the prototypes were created and tested with this technique in mind and example screenshots of key concepts can be seen below.

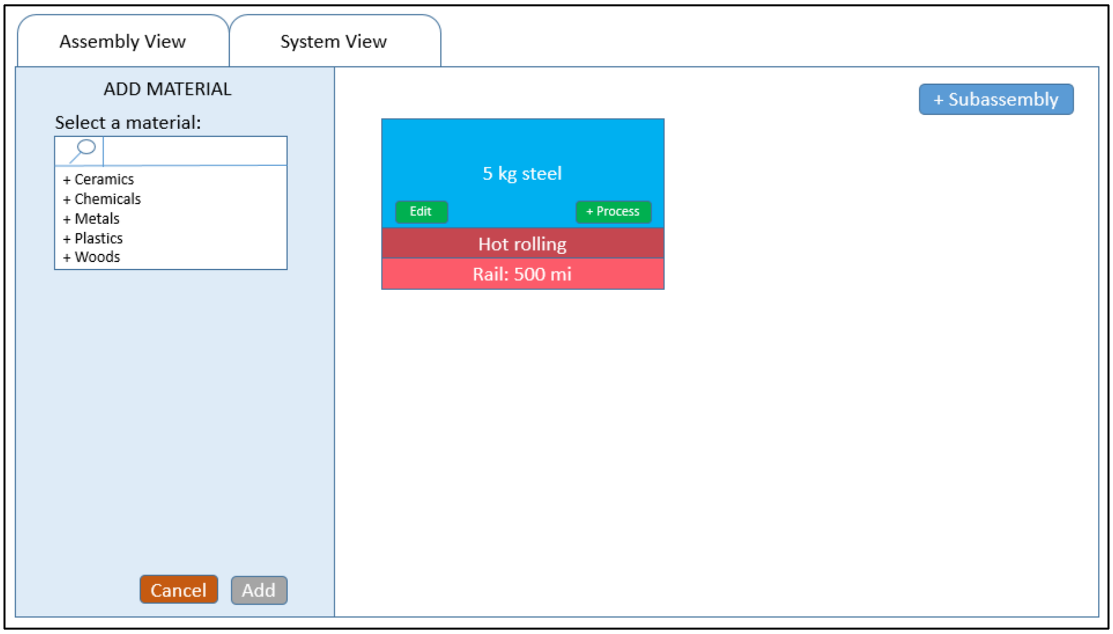
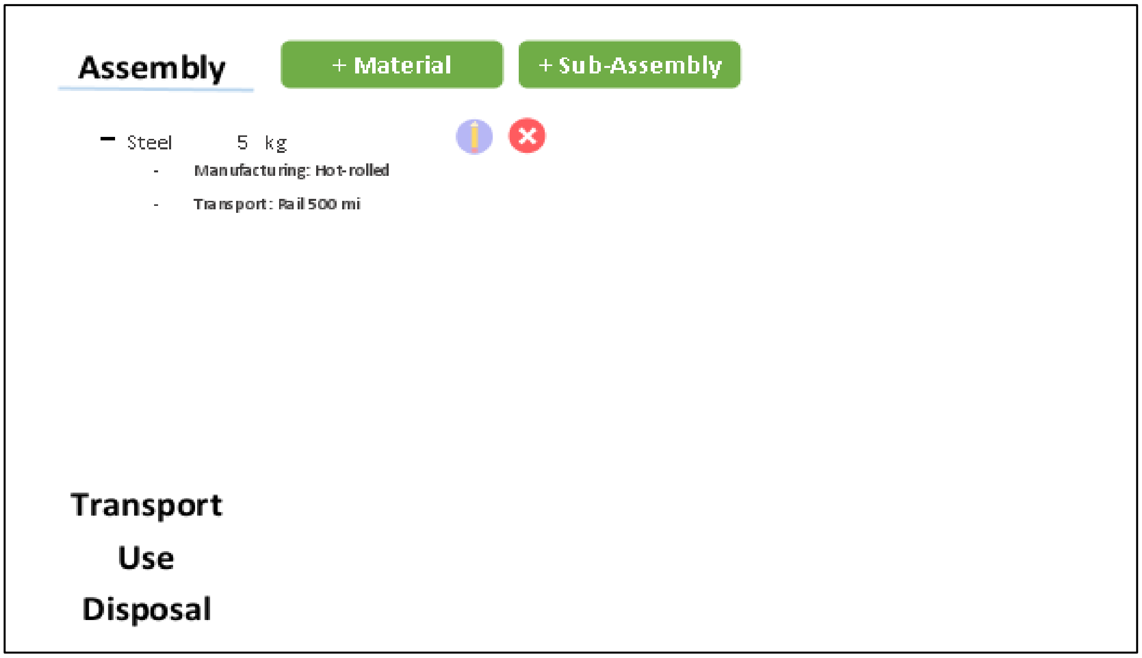
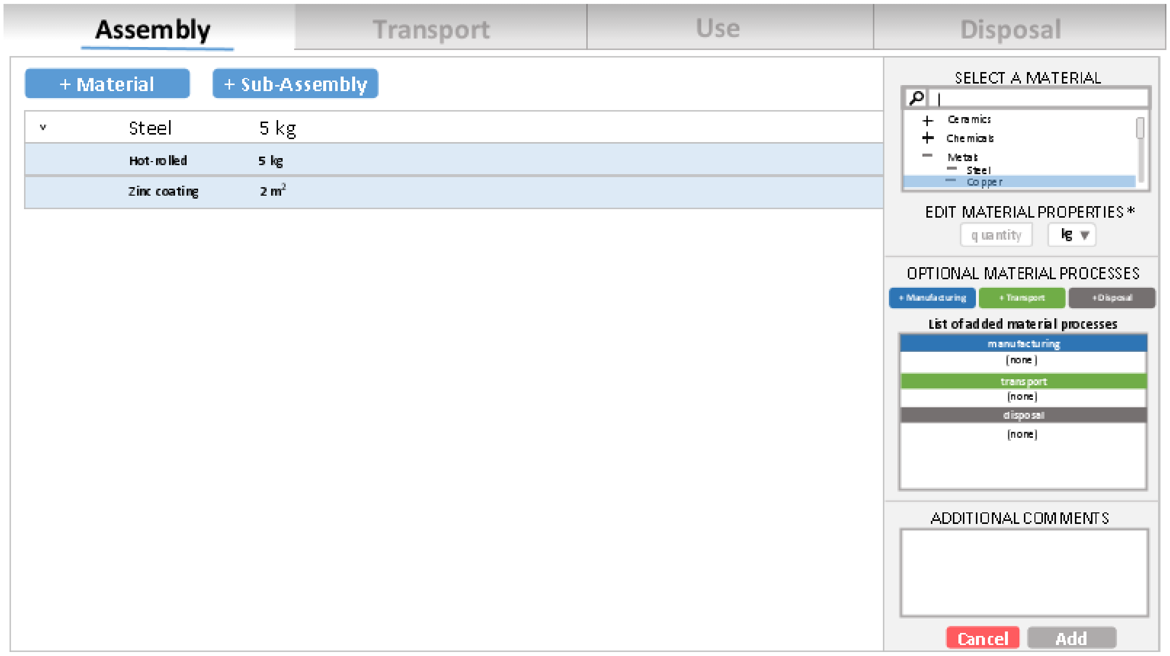


Figure 4a. Iteration 2 workspace format with direct manipulation of draggable components and constant library.



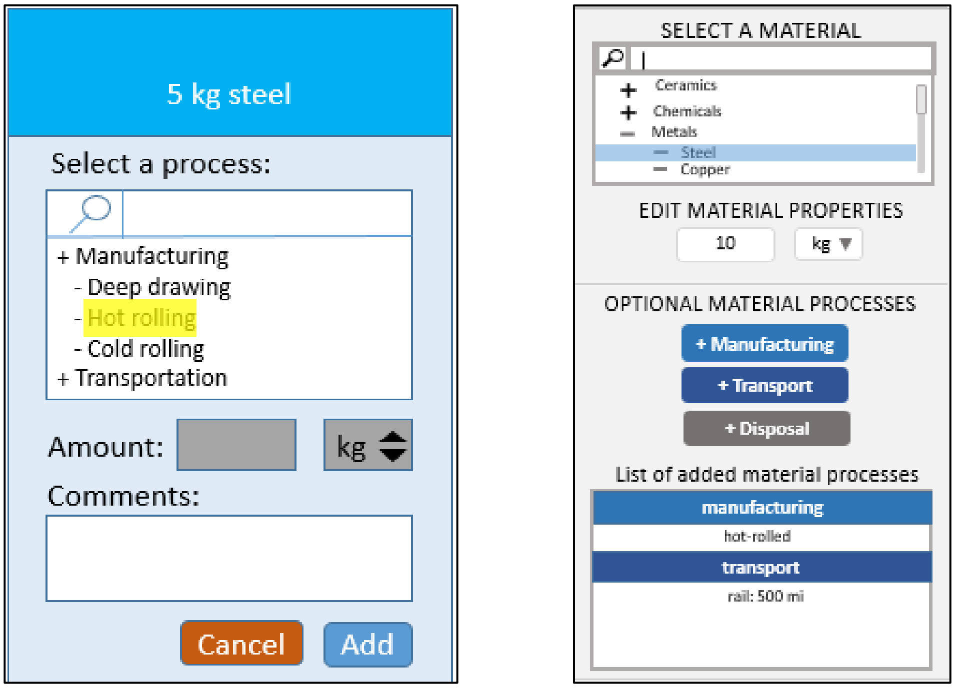
Steel 5 kg
- Manufacturing: Hot-rolled
- Transport: Rail 500 mi

Figure 4b. Iteration 2 list format of added components with life cycle tabs.



Steel	5 kg
Hot-rolled	5 kg
Zinc coating	2 m^2

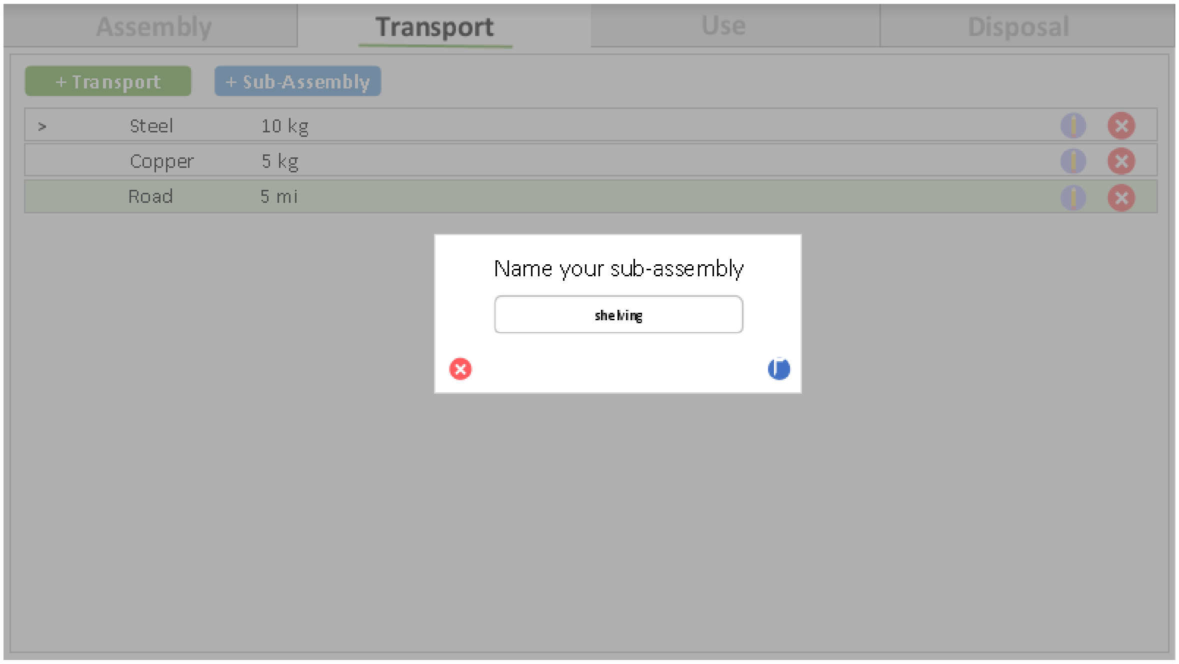
Figure 4c. Iteration 3 list format of added components with clarified life cycle tabs.



(a) One-by-one association of a process with a model component

(b) One-shot association of processes with a model component

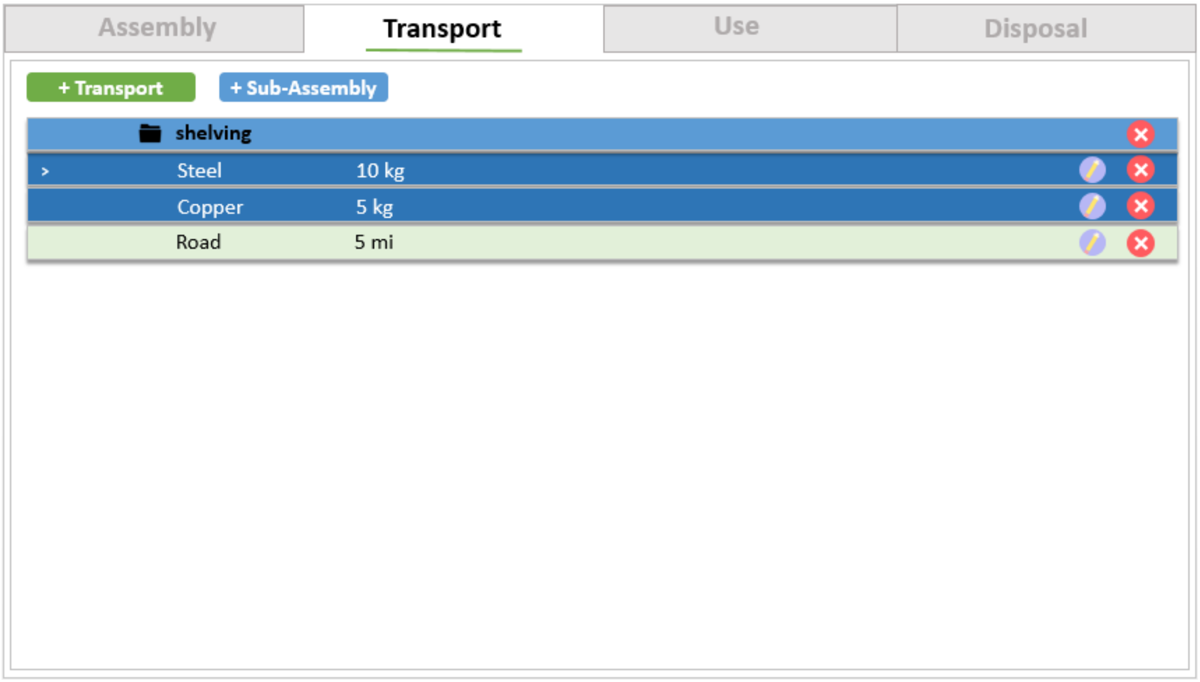
Figure 5. Designs to streamline component associations.



>	Steel	10 kg
	Copper	5 kg
	Road	5 mi

shelving

Figure 6a. Naming a sub-assembly after clicking the add sub-assembly button.



shelving		
>	Steel	10 kg
	Copper	5 kg
	Road	5 mi

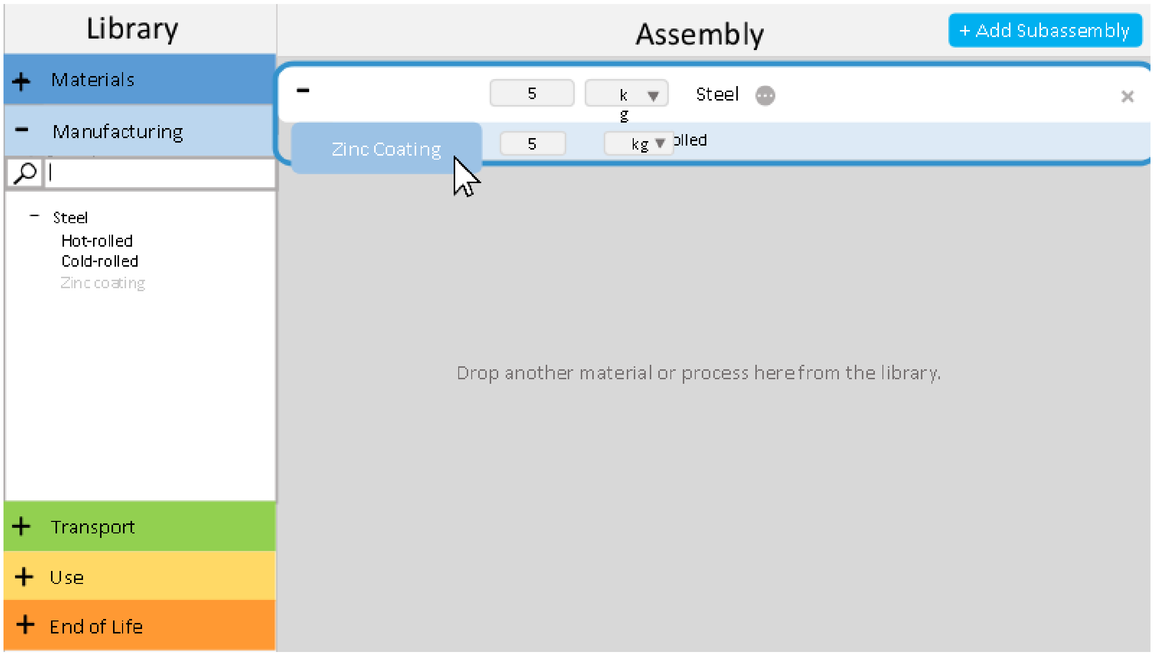
Figure 6b. Selecting items using shift to add to created sub-assembly.

Going from the second to third iteration, we were able to narrow the general layout in favor of the list view with life cycle tabs but wanted to maintain the direct manipulation seen in the workspace view. Users thought that the clear division of the library into life cycle categories (Figure 4b) was helpful in organizing their model but commented that the tabs lacked visual cues to suggest functionality. This was clarified in the third iteration as can be seen in Figure 4c.

For the process of streamlining component associations, users commented that the similarity of the one-shot addition prototype (Figure 5b) to Autodesk panels made the process intuitive and quick to navigate. However, the prototype was also criticized due to having only a small fraction of the screen be the user's locus of attention as well as overlaying the panel on the model. They mentioned that this was not an issue seen in the workspace prototype where objects could be directly manipulated and dragged around (Figure 4a), as the library supplemented the model rather than forcing the user to focus on a particular part of the screen.

Lastly, for grouping, users suggested to maintain conventional methods such as dragging over several objects or using shift and ctrl to select multiple items then dragging the selection into respective folders.

Variations of an updated prototype (see representative example in Figure 7) that addressed much of the feedback was user tested. These prototypes included a library pane from which the user could drag processes into the model/assembly. The model was organized in a list format but components could be dragged to reorder or associate. This allowed for not only guidance in inputting processes but also resolved issues of utilizing screen space efficiently. Furthermore, to allow for flexibility in use, one-by-one association of grouped components was favored over one-shot association. Ultimately, Figure 7 depicts the design obtained from multiple rounds of the design cycle.



Drop another material or process here from the library.

Figure 7. Iteration 3 workspace format with direct manipulation of draggable components in a listed organization and constant library.

2.2 Data visualization prototypes uncovered how best to accurately represent environmental impacts

Life cycle assessment is based off of collected environmental impacts from a variety of sources whose values intrinsically have uncertainty. While current LCA software solutions offer many views of environmental impacts, there are none that emphasize the major role that uncertainty plays in assessing the degree of impact. For instance, a component may seemingly have the largest impact but a high degree of uncertainty associated with that value would tell a different story. On the other hand, large uncertainty in a single component may be of less importance in the decision making process if the component does not have as great of an environmental impact as another component. The nuanced role that uncertainty plays in analyzing LCA outputs provides the opportunity to offer users an improved workflow. This is done by allowing non-specific inputs that are traditionally umbrella categories in other LCA software. For example, a user may choose to model "metals" rather than specifying "chromium steel production". The uncertainty of these non-specific inputs is taken as the min to max range of its children inputs. By allowing such inputs, users can save time by not needing to know the specifics of their model and get a rough estimate on environmental impacts before figuring out what components need to be refined and specified.

The overall environmental impact of a model can be calculated and normalized using a variety of methodologies. These methodologies typically generate midpoint scores for different categories of environmental impact such as ozone depletion, water consumption, etc. and can be normalized to output a single endpoint score. For the sake of simplicity, the single score method ReCiPe Endpoint (Goedkoop et al., 2013) was emulated for the purposes of data visualization prototyping. Feedback was obtained on unstacked or stacked representations of these scores (Figure 8), as well as on drilldown variations in which a user could click a region of interest and obtain more information on the components that fed into it. The latter included side by side drilldowns (Figure 9) as well as drilldowns that would regenerate the existing graph.

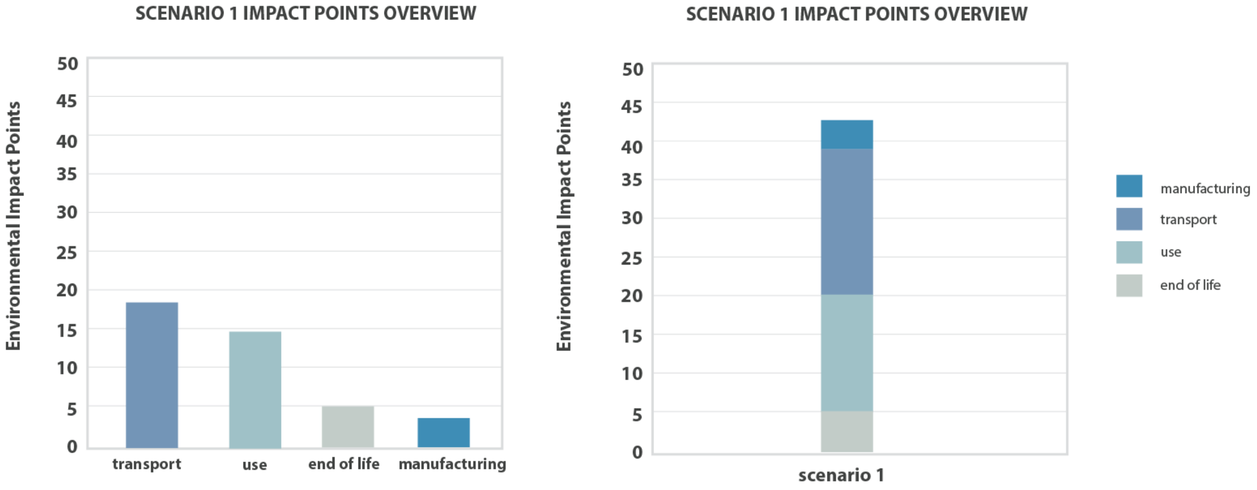


Figure 8. Unstacked (left) vs. stacked (right) prototypes of impact visualization.

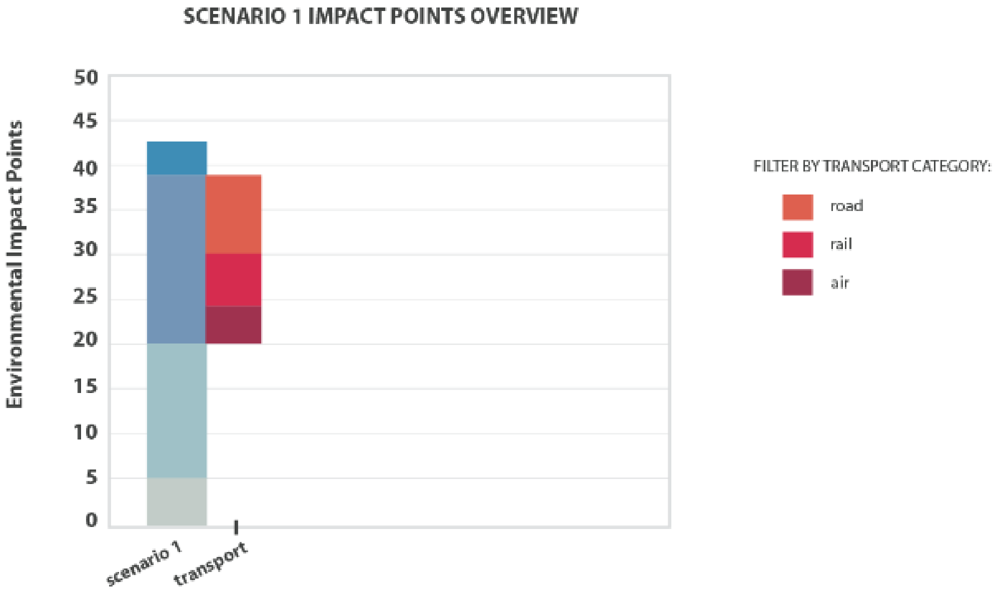
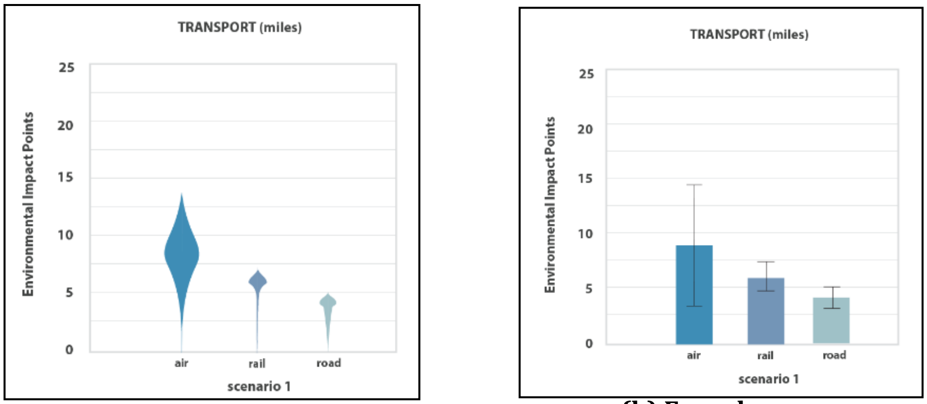


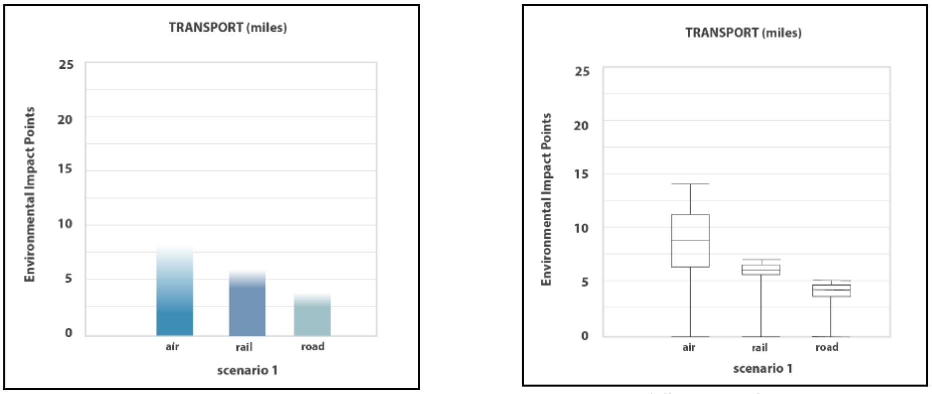
Figure 9. Side-by-side drilldown of transportation components.

Users agreed that the more views of environmental impact scores, the better, allowing for flexibility and greater comprehensiveness. For the side-by-side drilldown interaction, users were concerned with the fixed height of each successive layer, particularly if a subcategory had many components. While it was proposed that the next layer be a full height bar, users commented that this would be confusing as it destroys association with the previous layer.

As aforementioned, addressing the uncertainty in environmental impact scores would enable our users to make more well-informed decisions. Because the proposed change in workflow is dependent on the user's understanding of uncertainty, various representations of uncertainty were mocked up to identify what kind of form would resonate the most (Figure 10).



(a) Violin Plot **(b) Error bars**



(c) Blurred bars **(d) Box plots**

Figure 10. Representations of uncertainty for environmental impacts

Overall, the violin and box plots confused many users due to the display of data distribution on top of uncertainty. One issue that arose was in explaining the role of uncertainty to the target user group, many of whom have never used LCA software. A misunderstanding of the purpose of the uncertainty assessment graph versus that of the impact assessment may have caused skewed results. Ultimately, users preferred distinct error boundaries as given by error bars rather than the blurred-top prototype due to the inability to determine the exact environmental impact. This misunderstanding could have been mitigated by presenting the uncertainty assessment graphs next to impact assessment graphs to indicate their role as a supplement to the latter. To accommodate user preference for distinct error bounds but to expressly avoid confusion with environmental impact graphs and error distributions, we compromised with candlestick representation which can be seen later in Figure 13.

3 Implementation of data visualization design

As aforementioned, responsibilities for the implementation phase were split between user interface for model building and for data visualization. During the design phase, we were lucky to have a UC Berkeley undergraduate course, CS169, software engineering team simultaneously build interactive mock ups in Ruby on Rails of our most promising designs during the latter iterations for the model building. This is discussed along with further implementation work in my teammate Jonya's paper, whereas implementation details behind data visualization will be the topic of the remainder of this paper.

Many environmental impact datasets exist under license for use in LCA software. While we had access to EcoSpold 2 data (Meinshausen, 2016), importing it into a well-structure database from scratch would be time consuming. One particular Python framework known as Brightway2 was extremely promising due to its ability to setup a SQLite3 database from imported .SPOLD files as well as for its calculation engine. However, porting and modifying the framework for use in our Ruby on Rails application was the main obstacle. After talking with its creator, Chris Mutel, we decided that, while possible, the time would be better spent focusing on displaying the concept of uncertainty assessment with a dummy database (see Figure 11 for table definitions) rather than working on obtaining real data.

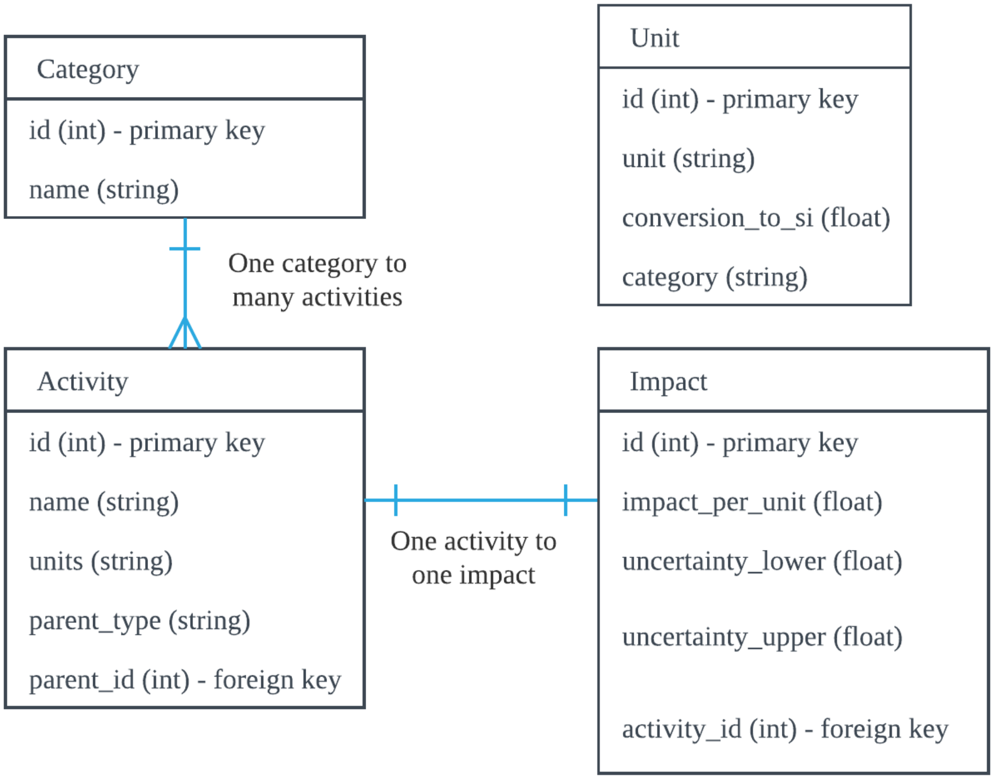
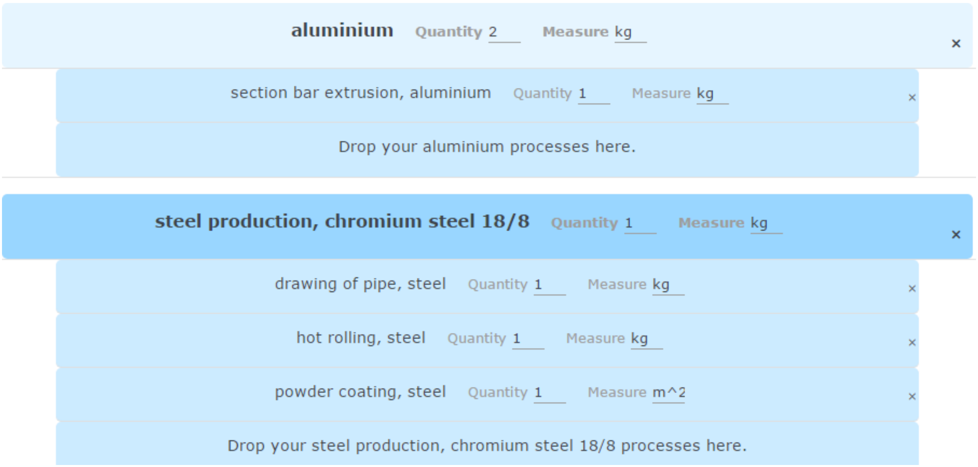


Figure 11. Database table definitions and entity relationships.

The dummy database consists of 4 tables: category, activity, impact, and unit. In this schema, there are 5 categories corresponding to the different life cycle components:

materials, processes, transport, use, and end of life. All library items are referred to as activities which can belong to either a particular category or another activity. For example, the activity “aluminum” would be a child of the activity “metals”, while the activity “metals” would be a child of the category “materials”. This is set polymorphically such that an activity or category is referenced by the same “parent type” attribute in the activity table, regardless to which table the parent belongs. The specific parent is linked by the foreign key “parent ID” in the activity table. Each activity also has an impact record associated with it. These records specify a randomized impact per default unit of activity as well upper and lower bounds per unit for the error. Lastly, there is a unit table containing possible inputs during model building with their conversion factor to SI units and the unit’s category (i.e. mass, length, etc.). This allows for not only flexibility is unit options but also filtered options depending on category when activities are inputted into the model.

For data visualization, the GoogleCharts JavaScript library was used. One challenge in graphing the data was its intrinsically hierarchical structure on the model building side. In order to preserve the hierarchical associations, each activity’s data was stored in a hash with a key reference to an array of children activity hash objects. This supported drilldown functionality during graphing such that the user could click on a bar of interest and generate a new graph displaying the children of the clicked bar on the x-axis. Figure 12 shows an example of this where the steel production bar was clicked resulting in a breakdown of the processes associated with it.



aluminium Quantity 2 Measure kg ×

section bar extrusion, aluminium Quantity 1 Measure kg ×

Drop your aluminium processes here.

steel production, chromium steel 18/8 Quantity 1 Measure kg ×

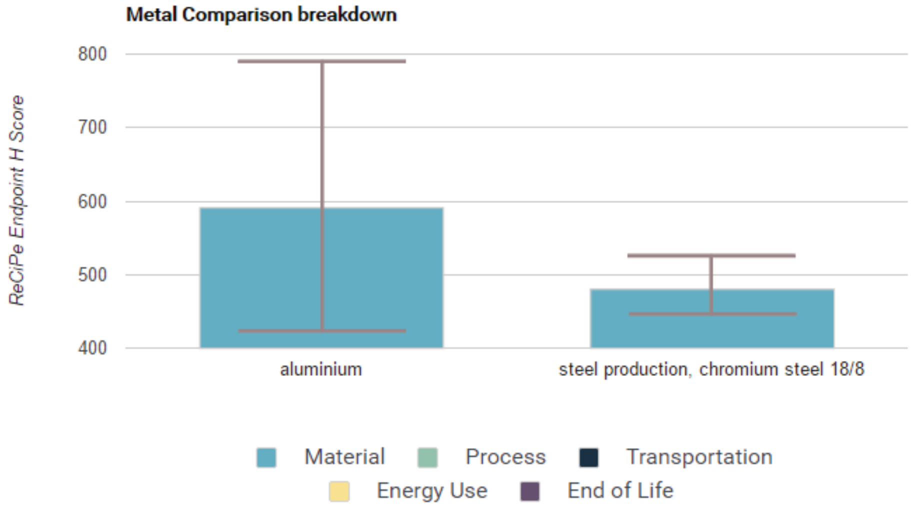
drawing of pipe, steel Quantity 1 Measure kg ×

hot rolling, steel Quantity 1 Measure kg ×

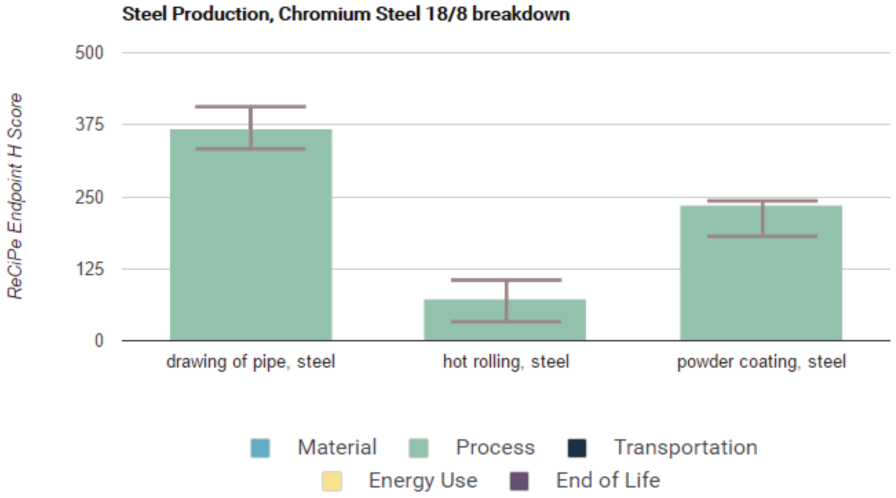
powder coating, steel Quantity 1 Measure m^2 ×

Drop your steel production, chromium steel 18/8 processes here.

(a) Example model with processes associated with top tier materials



(b) Model breakdown of environmental impacts for top tier materials



(c) Model breakdown of steel production, chromium steel 18/8 after clicking on its bar in (b)

Figure 12. Drilldown function – generating new graphs of children activities based on selected bar

The concept of uncertainty assessment is best used in the context where the user is not sure about the exact input. However, these nonspecific inputs (for example "ferrous" metal in place of "chromium steel") do not have measured environmental impacts. To model potential impact of these inputs, the average of its children activities was taken as the bar height with the error bounds spanning their error range. Thus, in comparison to a specific input, the nonspecific input would have a much larger error bound as can be seen in Figure 13. In addition, the uncertainty bars were color coded based on percent error to facilitate uncertainty assessment.

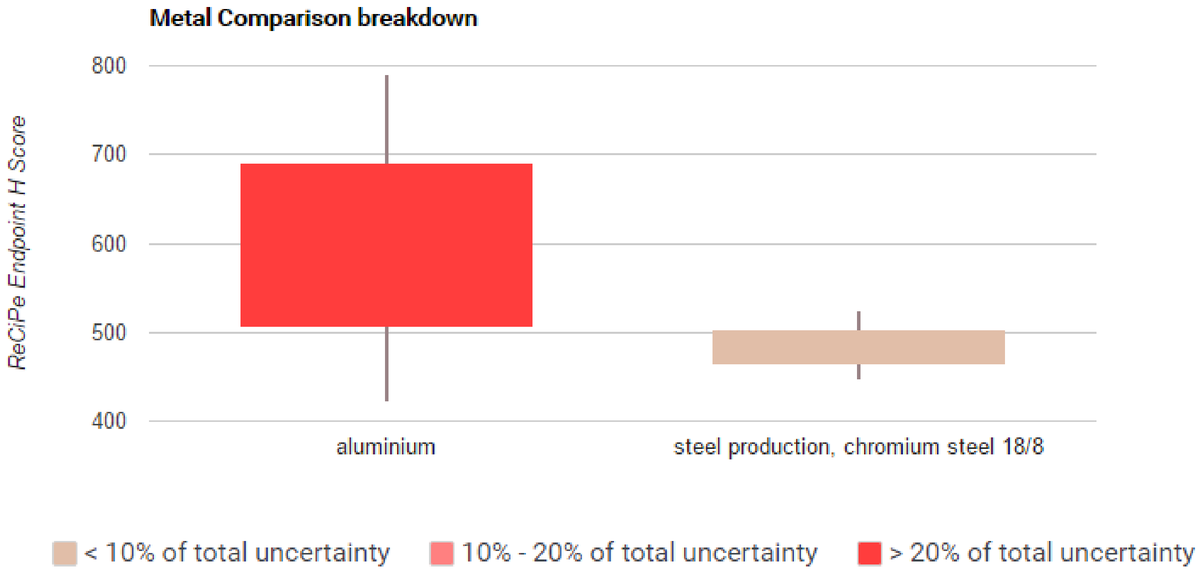


Figure 13. Uncertainty comparison between nonspecific aluminum input and specific steel input.

This assessment promotes a quick, initial modeling to identify the impacts that weigh most heavily, followed by a more refined modeling where large impact activities are specified in more detail. As much of the LCA process takes place off screen (collecting specifics about the system the user is modeling), this saves users time in identifying the activities that need to be specified.

4 Technical contribution conclusion and future steps

In an effort to improve software solutions for LCA which have either complex user interfaces or overly simplistic data visualization, we created a new LCA web application using Ruby on Rails. Through the iterative design cycle, we were able to explore different concepts of modeling a system and displaying its component environmental impacts. The resulting designs led to a drag and drop from a library of activities to a model pane. These activities could be associated with each other by dropping on top of existing entities in the model pane. The simplicity was a drastic divergence from current software which overly crowd the user's focus of attention with a plethora of option icons and multiple windows.

In addition, we proposed to improve data visualization and overall workflow by offering a more comprehensive assessment of the returned environmental impacts. This involved allowing users to model nonspecific inputs and displaying not only an estimated environmental impact but also its associated uncertainty. Ultimately, we hoped that this would speed up the process of collecting the specific inputs that current software require.

There is still room for major improvement. One area would be in allowing users to import their own public or private datasets, which would require importers for popular file formats such as SPOLD, XML, and CSV, as well as possibly restructuring the database to better support expected inputs.

Additionally, LCA can use a variety of different calculation standards, some of which are not single score such as the emulated ReCiPe Endpoint H in our prototypes. The calculation engine and data visualization can be expanded upon to be more robust and display multiple environmental impact midpoints (for example water toxicity, carbon emission, etc.) of each component on the same graph. Other forms of graphical representations can also be implemented such as Sankey diagrams.

Beyond model building and data visualization, defining the scope of the project and assessment boundaries are also important aspects of conducting LCA. Allowing for project description inputs or comments on model inputs would be extremely useful, particularly for users who intend to doubly use the software as a form of documentation for pursuance of environmental certification standards such as ISO or EMAS (see Part II for further discussion).

Regardless of additional features that may be added to the software, user testing would have to be conducted on a less homogenous pool to ensure that it meets the needs of our target user. User testing can also be used to qualify/quantify the proposed change in workflow.

Part II: Contextual Assessment

1 Introduction

In order to assess the ecosystem in which our software will be employed, this portion of the paper seeks to identify driving forces contributing to increased adoption rate of LCA software. It will identify market potential in small and medium enterprises (SMEs) by discussing the challenges they face and the benefits they gain in pursuing environmental management systems (EMS). Particularly, it will explore our software's position in aiding SMEs in acquiring EMS standard certifications. Then, the packaging industry will be analyzed in-depth to further illustrate the potential to improve adoption rates, allowing us to further determine the best strategy to position and market our LCA software across industries.

2 Shifting towards sustainability and the small/medium enterprise struggle

As global concern with the negative impacts of development on the environment increasingly unveils itself in consumer mindsets with the upswing of green products, small and medium enterprises (SMEs) have struggled to keep up with the trend towards sustainability. Despite making up 99% of all businesses and contributing to the majority of industrial pollution in the European Union (European Commission, 2012), only 25% of SMEs in the EU, and even less in the US, actually use environmental management systems (EMS) to aid in achieving sustainability goals (European Commission, 2012). However, SMEs that do take part in green initiatives attribute their need of doing so to meet consumer demand (European Commission, 2012). This clear discordance highlights issues SMEs face in adopting EMS.

The challenge for SMEs to take part in EMS is largely due to knowledge gaps and high implementation costs in light of their limited capital. The lack of information is multifaceted and stems from not being able to accurately track environmental impact metrics, such as energy use (Henriques and Catarino, 2016), to having a poor understanding of the various EMS options and their implementation logistics (Hillary 2004). In order to amass all of this information, resources are spent on training programs for current employees (Henriques and Catarino, 2016) or on hiring consultants to help navigate environmental regulation and EMS standard certification requirements (Hillary, 2004). The upfront financial strain as a barrier to EMS implementation is, however, offset by various benefits. Most notably, SMEs incorporating them in their business strategies have indicated associated cost reductions from becoming more energy efficient and avoiding penalties accrued from lack of compliance with environmental regulations (Morrow and Rondinelli, 2002). Aside from economic benefits, SMEs can also better their public image, which can help companies attract and maintain customers (Hillary, 2004).

3 EMS standard certification and the potential of LCA

The scarce use of EMS by SMEs, despite increasing consumer demand for sustainability, presents a clear opportunity to create tools that aid in the process of EMS standard certification. Currently, there are two major international standards that act as guidelines for EMS implementation: ISO 14001 by the International Organization for Standardization and the European Eco-Management and Audit Scheme (EMAS) (Morrow and Rondinelli, 2012). Both standards provide guidance in assessing environmental impacts on a system-wide scale, and thus lend themselves particularly well for life cycle thinking and assessment.

In spite of this, the actual extent of LCA use to aid in EMS and EMS standard certification is sporadic as reported by a study conducted in Poland, Sweden, and Germany (Lewandowska et al., 2013). Although most of the companies generally agreed that LCA software is widely available, they did not primarily use it as part of the EMS standard certification process due to its time-consuming nature (Lewandowska et al., 2013). This indicates that a solution to streamline LCA workflow has potential to increase its adoption in pursuit of EMS standard certification. In turn, EMS standard compliance affords the benefits prior mentioned to SMEs, which are pressured to quantify their environmental impacts by the propulsion of sustainability into the mainstream.

4 Case study: Analyzing the packaging industry

As seen above, there is potential for simplified LCA software to benefit SMEs to aid in EMS standard certification, ultimately allowing them to achieve sustainability goals with the added benefit of cost reduction. To complement this idea, we can perform a more in-depth look at how a specific industry, the packaging industry, can adopt similar LCA processes to stay up-to-date with customer concern for industrial impact on the environment by creating greener products.

The packaging industry has generally been consistent and stable, with growing demand for packaging as consumer spending increases. A powerful segment in this industry is food packaging. The creation of new food packaging has increased 89.3% within only a five year span between 2009 - 2014 (Topper, 2014). Moreover, the percentage of new products has declined 37.5% (Topper, 2014), indicating that companies are now deciding to repackage existing products to attract new customers. The competition in this industry is high, as a majority of packaging industry operators are small businesses (Robert, 2016). There is also low capital investment necessary for companies to enter the market, resulting in a low level of concentration, with "the top companies estimated to account for less than 14% of industry revenue in 2016" (Robert, 2016). As a result, the food packaging companies are constantly looking for ways to position themselves in the already popular and competitive market.

5 Sustainable packaging as a differentiator

One way for food packaging companies to differentiate their product is to offer more sustainable packaging options. According to recent marketing research, more than 53% of consumers say that packaging indicating environmental or sustainability efforts is important to them (Topper, 2014). They believe that the more environmentally friendly a product is, the more likely they're influenced to buy that product over another (Topper, 2014). People care about being green - in fact, a majority of the population (73%) believe that each of us has an obligation to be environmentally responsible (Levesque, 2013). Companies that strive to be sustainable can not only stay ethical, but also attract customers to benefit business. Furthermore, green packaging is very important amongst high-income customers. A 2013 marketing study showed that customers who earn more than $150K are more likely to purchase a food product that has environmentally friendly packaging (Levesque, 2013). Therefore, companies should consider pursuing more environmentally friendly packaging in order to generate a higher value of quality and maintain their business from higher-income consumers.

6 Adopting LCA tools strategically for sustainable packaging

How do these companies in the food packaging market find ways to create more environmentally friendly packaging? One powerful technique is through the use of LCA software. By performing a quantitative evaluation of a food package's environmental performance across its life cycle, companies can leverage their sustainable awareness and also further differentiate their products versus other competitors in the market. Upon researching which tools currently exist for analyzing sustainable packaging, the most common one is PIQET (Verghese et al., 2010). If we were to commercialize our capstone technology, we could strategically position our product so that it's attractive to other markets in a way that's similar to currently existing options for the food packaging market, such as PIQET. However, our interface will be a more updated and user-friendly version, allowing us to market ourselves as a tool that can be utilized even without prior LCA knowledge. The utilized strategy involves using market segmentation to target smaller groups of users that could benefit from our product directly and advance them to leaders within their own industries.

7 Contextual assessment conclusion

Overall, LCA tools prove to be very useful for markets such as the food packaging industry. It not only helps differentiate products, but also provides powerful information to create the most sustainable packaging. Similar benefits could also apply to other markets, resulting in a further potential need for a more intuitive way to build models and create data visualizations. Ultimately, we hope that users from all different industries can adopt our streamlined LCA software as a useful way to reduce systematic impacts and produce greener products.

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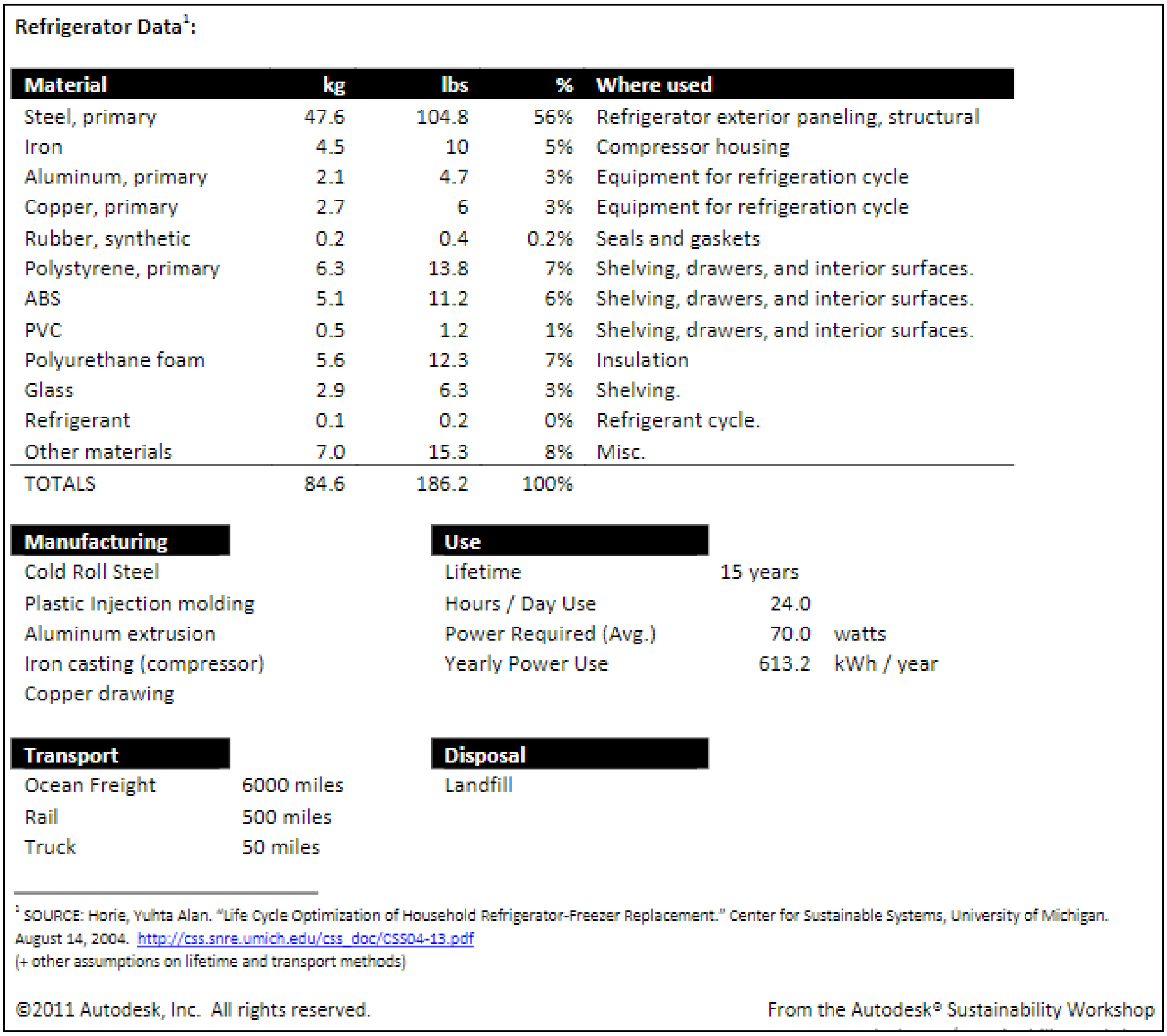
Appendix A – Model Building Design Phase 1



Refrigerator Data[1]:

Material	kg	lbs	%	Where used
Steel, primary	47.6	104.8	56%	Refrigerator exterior paneling, structural
Iron	4.5	10	5%	Compressor housing
Aluminum, primary	2.1	4.7	3%	Equipment for refrigeration cycle
Copper, primary	2.7	6	3%	Equipment for refrigeration cycle
Rubber, synthetic	0.2	0.4	0.2%	Seals and gaskets
Polystyrene, primary	6.3	13.8	7%	Shelving, drawers, and interior surfaces.
ABS	5.1	11.2	6%	Shelving, drawers, and interior surfaces.
PVC	0.5	1.2	1%	Shelving, drawers, and interior surfaces.
Polyurethane foam	5.6	12.3	7%	Insulation
Glass	2.9	6.3	3%	Shelving.
Refrigerant	0.1	0.2	0%	Refrigerant cycle.
Other materials	7.0	15.3	8%	Misc.
TOTALS	84.6	186.2	100%	

Manufacturing

- Cold Roll Steel
- Plastic Injection molding
- Aluminum extrusion
- Iron casting (compressor)
- Copper drawing

Use		
Lifetime	15 years	
Hours / Day Use	24.0	
Power Required (Avg.)	70.0	watts
Yearly Power Use	613.2	kWh / year

Transport	
Ocean Freight	6000 miles
Rail	500 miles
Truck	50 miles

Disposal

Landfill

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[1] SOURCE: Horie, Yuhta Alan. "Life Cycle Optimization of Household Refrigerator-Freezer Replacement." Center for Sustainable Systems, University of Michigan. August 14, 2004. http://css.snre.umich.edu/css_doc/CSS04-13.pdf
(+ other assumptions on lifetime and transport methods)

From the Autodesk® Sustainability Workshop

Figure A.1. User testing refrigerator bill of materials and associated life cycle processes.

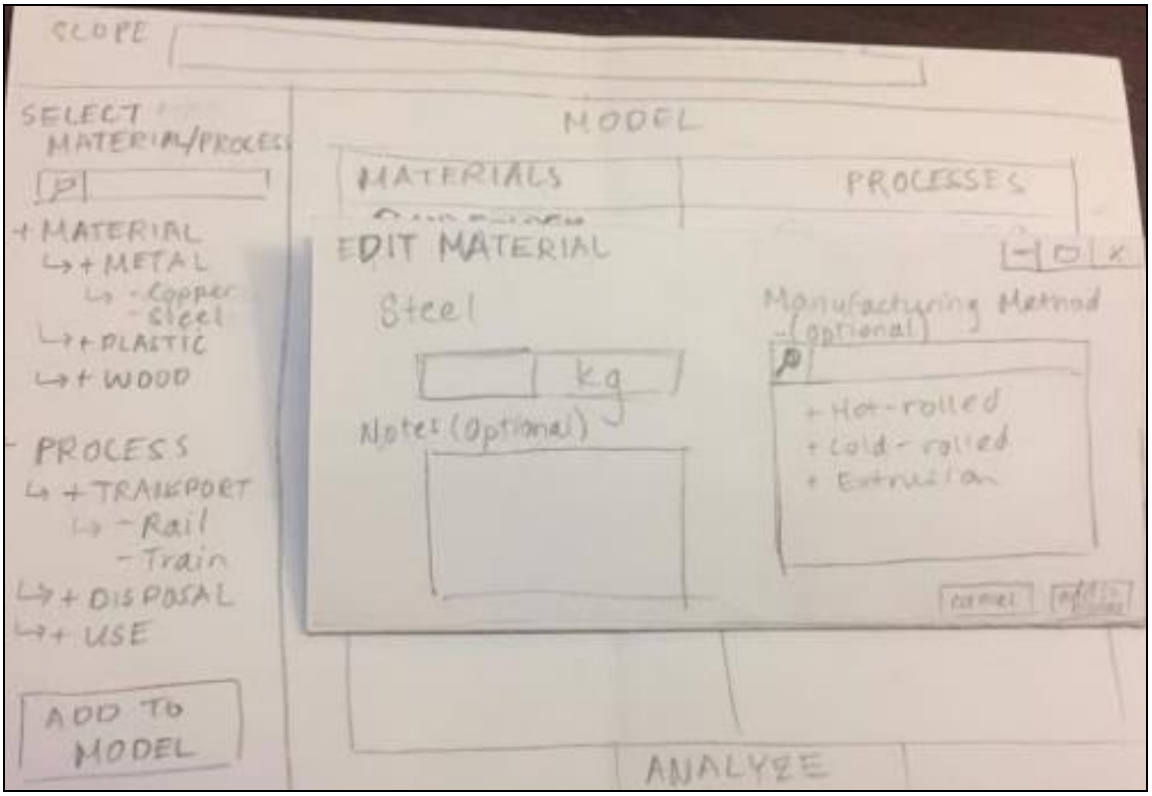

Figure A.2. Adding a material to the model with associated processes and full library view.

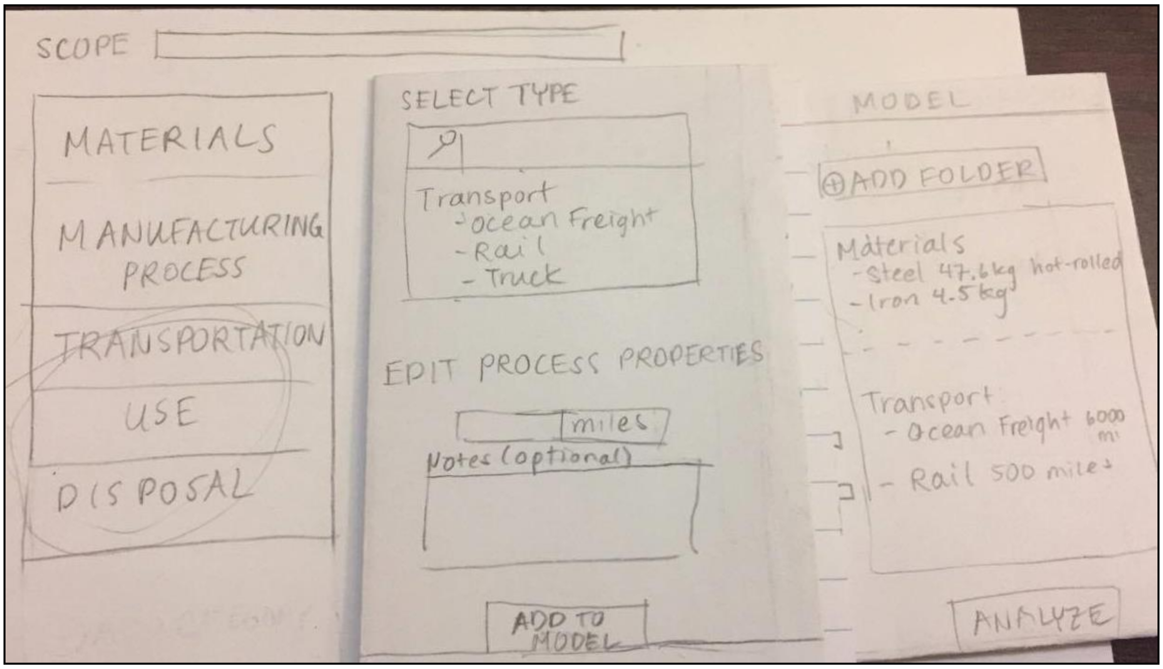

Figure A.3. Adding a life cycle process to model using distinguished life cycle tabs.

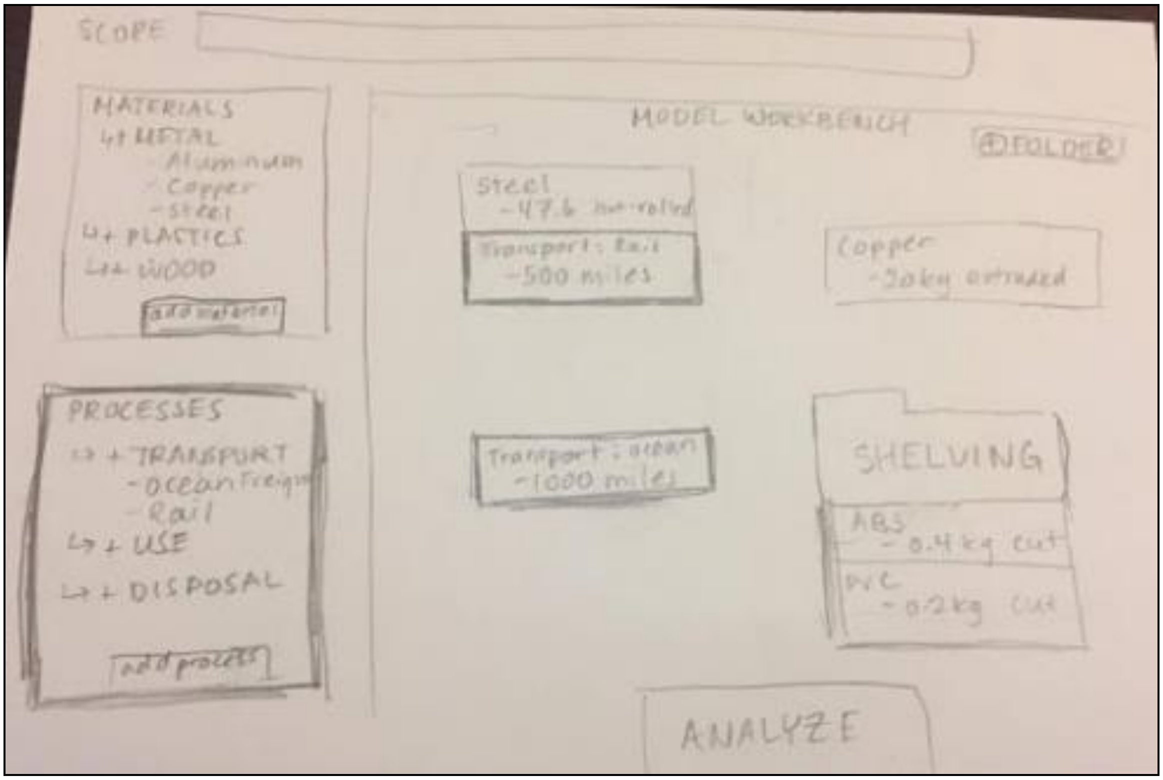

Figure A.4. Workspace format with material/process blocks that could be snapped together.