2021 OENG1118 Sustainable Engineering Practice and Design

Week 3 & 4 – Engineering Design for Sustainability

Workbook

Note: Blue text is text that is new to its section.

Contents

Design skills

Our **task** is to (re)design a solution with better sustainability performance than the conventional solution has. Luckily, creative engineers and other designers have developed many methods to design solutions that are closer to being sustainable than our conventional solutions are. We'll learn a small set of **design skills** that key enables of engineering design for sustainability and are also relevant to most engineering projects.

In **project deliverables** (Design Deliverable and Complete Deliverable), we hope to see *demonstrations* the design skills because we want to check that you can *do* things. We don't need to see summaries of the theory about a skill because we already know the theory.

In your deliverable, make it clear where you're demonstrating each skill. Consider using subheadings, bold font, feature boxes, summary diagrams, or other signposting devices.

The **grade** that a project deliverable earns depends largely on the *extent* of the demonstrations. That is, you demonstrate that:

- *Credit*: you apply each skill correctly, in isolation from other skills, in the domains that we cover in class. Such demonstrations score average grades because they do only what we've asked.
- *Distinction*: you've learned how the skills relate and apply them accordingly.
- *High distinction*: you've learned how the principles of the skills so deeply that you adapt them to domains that we don't cover in class.

Below are some examples of project-level **extensions**. The later sections of this workbook present examples of skill-level extensions.

Distinction

- Tell a single, consistent, congruent story. Design a solution such that you can demonstrate all skills. You'll probably end up changing some areas of focus as we progress through the semester. For example, you might initially develop a technological solution and then identify a leverage point in the users' behaviour. In this case, you might change your focus and enhance the education components your solution. You'll need to iterate non-linearly through the skills.
- Collect some primary data. For example, you might survey the users of your product or system.

High Distinction

- Apply our skills to a service, like education, health care, or mobility.
- Apply our skills to a process, like your project management. For example, you might aim to design a sustainable process for the development of your project deliverables.

You're welcome to apply a skill only once, perhaps to a single subsystem or component. You don't need to (but you may) reapply that skill to another subsystem. Repetition of the skills attracts no extra marks but could be useful to demonstrate extensions of the skills.

The verb in the skill indicates the expected **depth of application**, as indicated in the Table 1.

Table 1: Expected depth of application of skills according to verbs.

Verb	Depth of application
State	Write/say a sentence, or show the thing
Draw	Show a picture
List	State multiple things, possibly in a sequence
Calculate	Quantify parameters and show mathematical working out
Give examples	State/show examples (you might already know or create the examples)
Identify	Find (you might need to search) and state/show the thing
Describe	Address the what, when, and who of the thing
Explain	Address the what, when, who, why, and how of the thing
Discuss	Present data and opinions, state the advantages and disadvantages
Construct	Make a thing by following instructions
Create Formulate	Make a new thing, possibly by combining existing things
Justify	Present evidence, probably citing sources
Assess	Identify correct/good things, incorrect/bad things, and opportunities to improve things based on your critical review of information and evidence
Evaluate	Make a value judgement based on your critical review of information and evidence
Plan	Present a procedure, describe the activities, show a timeline, list the required resources, present the tools, assess the risks, etc.

0. Systems

In this topic, we'll learn a few basics of:

- systems
- our design process.

We'll adopt a systems design process that include some methods and tools that lead us to develop solutions that are closer to being sustainable than our conventional solutions are. We'll borrow from the fields of systems engineering, engineering design, system dynamics, whole system design, eco-design, design for sustainability, and design for X. We'll cover the first three out of the four design phases:

1. Definition of Need
2. Conceptual Design
3. Preliminary Design
4. Detailed Design

Select a product

Normally, we'd avoid focussing on a product so soon in the design process. Instead, we'd explore the problem to determine the solution's requirements, then we'd determine whether the solution would benefit from a product, and finally we'd design the solution.

For OENG1118, though, you may choose a product of your interest to *re*design. The product should be:

- a single, specific, real thing (rather than a technology category)
- a complicated system, comprising at least three major interacting subsystems.

Examples of appropriate products:

- Vehicles: 2019 Nissan Leaf (rather than *an electric vehicle*)
- Travel: Tullamarine airport or Boeing 787 Dreamliner (rather than *an airport* or *an airplane*)
- Buildings: your home, with a known location, and a known number of bedrooms, bathrooms, car spaces, etc. (rather than *a house*)
- Fashion: the supply chain of men's, size-32, blue, denim jeans (rather than *clothes*)
- Smartphone: Samsung Galaxy S10 (rather than *a smartphone*)
- Solar panels: 1kW solar PV system installed on a flat roof in Melbourne (rather than *a solar panel*).

1. Definition of need

In this phase, we'll:

1. explore the potential of our solution
2. specify and quantify the requirements of our solution.

For your project deliverables, demonstrate all skills.

- Define sustainable development or regenerative development in the context of your product's life cycle
- Generate design requirements
- Compile non-overlapping sets of performance indicators
- Develop theoretical targets.

Define sustainable development or regenerative development in the context of your product's life cycle

We'll adapt a few concepts to clarify *sustainable development and regenerative development* in the context of the problem.

Base task**:** Communicate your Project Group's definition of sustainable development as it relates to your understanding of the problem by considering time, space, uncertainty, system behaviour, and cumulative impacts.

Activity

Explain the potential for each subsystem of your system to be sustainable or regenerative. Address each of the three pillars of sustainability—economy, environment, and society.

As an example, consider the problem of *too little clean drinking water for a remote community*. Assuming that reducing the size of the community is not an option, our solution will probably need to collect and supply more water, or treat and recycle the existing contaminated water. To do those tasks, our solution could potentially:

- regenerate water quality because it upgrades the water quality
- regenerate community autonomy because hydrated, healthy people can work, study, and run community activities
- regenerate the local economy because people who work can earn an income and engage in trade
- regenerate energy stores because the unwanted contaminants contain energy. Later in the design process, we might determine that our solution can't safely extract the energy from the contaminants. So, our solution would be able to use energy only sustainably because we can preserve our non-renewable energy stores, but we can't create new energy (according to The First Law of Thermodynamics).

Given that potential, what would sustainability look like for the community?

Extension**:** Explain how the definition inspired the sustainability requirements; access other information to help develop a vision of sustainability; use a vision of your Project state of completion to guide your Project Group's decisions.

Generate design requirements

Having:

- explored and understood the breadth of the problem at the system level
- explored and understood the community's perception of the problem, and
- developed our understanding of sustainability in the context of the problem,

we are now prepared to create a short-list of the most important requirements that our solution should meet.

Base task: List the 5-10 design (customer and sustainability) requirements that your solution shall meet to deliver its function/service sustainably.

Activity

Generate 1-3 customer requirements that your solution shall meet. Complete the sentence, "The solution shall…" (What shall the solution do to solve the problem?) What is the required service? What are the operating conditions?

Generate 3-5 sustainability requirements that your solution shall meet, and that relate to sustainable or regenerative development. Complete the sentence, "The solution shall…" (What shall the solution do to be sustainable or regenerative?) What is the optimal service? Generate at least one requirement for each of the three pillars of sustainability—economy, environment, and society.

Extension: Justify the choice of requirements based on the annotated causal loop diagram, the vision of sustainability, or the characteristics of frugal innovation; explain how some sustainability requirements inspired a revision of the annotated causal loop diagram or of the vision of sustainability; use requirements to prioritise your Project Group's important tasks; use requirements to monitor your Project Group's progress.

Compile non-overlapping sets of design requirements and performance indicators

We'll select appropriate indicators that represent the requirements that our solution should meet.

Base task: List 1-3 performance indicators that measure each design requirement; and that are representative, reliable, feasible, and informative.

Activity

Compile 1-3 performance indicators for each design requirement. Where possible, make the indicators quantitative. State the indicator's name and units of measurement. Ensure that the indicator sets avoid overlap.

Extension: Justify the choice of performance indicators based on the vision of sustainability or the characteristics of frugal innovation; use performance indicators to monitor your Project Group's progress.

Develop theoretical targets

We'll determine targets for each sustainability indicator.

***Base task*:** Present, and explain how you developed, the theoretical targets for the performance indicators of the sustainability requirements.

Activity

Identify things (concepts, formula, equations, rules, tools, models, etc.) from your history of education that you could use to determine the theoretical targets for the performance indicators of the sustainability requirements.

Determine the theoretical target for each performance indicator of the sustainability requirements. Theoretical targets reflect the function of an ideal system, one without losses (e.g., without friction and leaks) and without resource limitations (e.g., without supply and processing delays). Where possible, make the targets quantitative. Most theoretical targets are maximums or minimums; few are ranges.

For the customer requirements, the target reflect the expected performance. There probably aren't any theoretical targets.

***Extension*:** Develop practical targets for resource consumption by superimposing practical constraints onto the theoretical targets; use targets to monitor your Project Group's progress.

Conclusion

We've now concluded our processes for the Definition of Need phase. We explored the potential of our solution, and specified and quantified the requirements of our solution. Next, we'll start our processes for the Conceptual Design phase.

2. Conceptual design

In this phase, we'll develop a conceptual solution by applying strategies that can give sustainable outcomes.

For your project deliverables, demonstrate *at least five of the seven* optional skills (as marked below and in the *Preliminary design* section). We've made some skills optional to accommodate the rare project problems for which 1-2 skills are difficult to apply. Even for those problems, get creative to demonstrate your understanding of the principles of the skills by adapting them to domains that we don't cover in class.

- Incorporate frugal subsystems and processes (optional)
- Incorporate biomimetic subsystems and processes (optional)
- Increase eco-efficiency (optional)
- Increase eco-effectiveness (optional)
- Identify leverage points using whole-systems thinking (optional).

Incorporate frugal subsystems and processes

We'll use a strategy called frugal innovation to introduce design options that decrease economic costs to sustainable levels while maintaining the primary functions.

Base task: Communicate your Project Group's brainstormed options for making your product sustainable, indicating the features that arose from the strategy of frugal innovation. You choose the format (words, diagram, etc.).

Activity

Recall the functional design requirements and subfunctions.

Distinguish between the essential requirements and subfunctions, and the non-essential requirements and subfunctions. As an example, consider the functions of a passenger vehicle. We could consider the requirement to *protect passengers from wind* as essential and the requirement to *protect passengers from noise* as non-essential.

Identify frugal options for each requirement and subfunction. Consider the characteristics, rules of thumb, and solution patterns in the lecture.

Apply selected options to the conceptual solution.

Extension: Justify the selected options based on the *Levels of regenerative systems* scale scale; use frugal innovation to streamline/simplify your Project Group's management or design process.

Incorporate biomimetic subsystems and processes

We'll use a strategy called biomimicry to introduce design options that are well adapted to a sustainable or regenerative biosphere.

Base task: Communicate your Project Group's brainstormed options for making your product sustainable, indicating the options that arose from the strategy of biomimicry. You choose the format (words, diagram, etc.).

Activity

Recall the functional design requirements and subfunctions.

Identify biomimetic options for each requirement and subfunction. Query the *AskNature* database. Consider the principles in the lecture.

Apply selected options to the conceptual solution.

Extension: Justify the selected options based on the *Levels of regenerative systems* scale; use a biomimetic process for your Project Group's design process or learning.

Increase eco-efficiency

We'll use a strategy called eco-efficiency to introduce design options that decrease the resource requirements to sustainable levels.

Base task: Communicate your Project Group's brainstormed options for making your product sustainable, indicating the options that arose from the strategy of eco-efficiency. You choose the format (words, diagram, etc.).

Activity

Recall the functional design requirements and subfunctions.

In your product, identify the subsystems with largest potential for an increase in eco-efficiency.

Identify eco-efficient options for each requirement, subfunction, and subsystem.

Apply selected options to the conceptual solution.

Extension: Justify the selected options based on the *Levels of regenerative systems* scale; use eco-efficiency to manage your Project Group's human and time resources.

Increase eco-effectiveness

We'll use a strategy called eco-effectiveness to introduce design options that increase the regenerative capacity.

Base task: Communicate your Project Group's brainstormed options for making your product sustainable, indicating the options that arose from the strategy of eco-effectiveness. You choose the format (words, diagram, etc.).

Activity

In the conceptual solution, identify the hardware that could be made of biological nutrients. As an example, consider a wood chipper. The chipping contact surface could be made from a biological nutrient like a bio-ceramic because it is subject to abrasion and loss. As small pieces of the surface are lost to air and then soil, they could have a benign or regenerative impact.

In the conceptual solution, identify the hardware that should be made of technical nutrients. Return to the wood chipper example. The wood chipper container could be made from a technical nutrient like steel because it should have a long useful lifetime. At the end of the wood chipper's useful life, the container could be directly reused to as part of another wood chipper.

Add those hardware options to the conceptual solution.

Extension: Justify the selected options based on the *Levels of regenerative systems* scale; use eco-efficiency to maximise your Project Group's learning.

Identify leverage points using whole-systems thinking

We'll use a strategy called whole-systems thinking to identify leverage points for meeting the design requirements.

Base task: Communicate your Project Group's brainstormed options for making your product sustainable, indicating the options that arose from the strategy of whole-systems thinking. You choose the format (words, diagram, etc.).

Activity

Identify the interactions between your solution system and its operating environment.

- As an example, consider a dwelling, like a house or an apartment. The house contains people, who flow between other types of infrastructure, such as the workplace, school, supermarket, and transport vehicles. Our immediate solution could be to improve the dwelling. Whole-systems thinking could instead lead us to relocate the people such that they lived closer to their workplace, school, and supermarket, decreasing the impacts from transport vehicles.
- As another example, consider a computer. The computer contains information in the form of bytes. On the upstream side, the information is in hardcopy documents or thoughts in the user's head. On the downstream side, the computer stores information in digital documents, computer models, and other digital artefacts. Our immediate solution could be to improve the computer. Whole-systems thinking could instead lead us to better organise our upstream information such that we generate only the required digital document, avoiding the impacts of generating and storing multiple documents.

Identify the leverage points for improving your conceptual solution's performance.

Identify options that improve your conceptual solution's performance.

Apply selected options to the conceptual solution.

Extension: Justify the selected options based on the *Levels of regenerative systems* scale; use whole-systems thinking to identify your Project Group's most important tasks.

Conclusion

We've now concluded our processes for the Conceptual Design phase. We generated a conceptual solution by applying strategies to give sustainable outcomes. Next, we'll start our processes for the Preliminary Design phase.

3. Preliminary design

In this phase, we'll develop our conceptual solution into a preliminary solution by optimising at the system level and designing at the subsystem level.

For your project deliverables, demonstrate *at least five of the seven* optional skills (as marked below and in the *Conceptual design* section).

- Follow the optimal design sequence (optional)
- Optimise the system lifetime (optional)

Follow the optimal design sequence

We'll use a set of design-sequence heuristics to optimise the preliminary solution at the system level.

Base task: Communicate your Project Group's optimised preliminary solution, indicating the features that arose from the application of the optimisation sequences and the optimisations of the resource-transmission paths. You choose the format (side-by-side comparison of preliminary solutions, description, etc.).

Activity

Identify at least one optimisation in your preliminary solution for each optimisation sequence.

Apply selected optimisations to your preliminary solution. Act on the *before* and the *after* subsystems. That is, optimise the *people* subsystem and the *hardware* subsystem, the *shell* subsystem and the *contents* subsystem, etc.

Identify at least one resource-transmission path in your preliminary solution.

Optimise resource use along selected paths.

For your project deliverables, demonstrate at least wo sequences.

Extension: Explain how a single optimisation results in improvements against multiple design requirements; explain how a single optimisation results in lower consumption of multiple resources; apply multiple design sequences simultaneously; distinguish between improvements in *after* subsystems that occur automatically and potential improvements in *after* subsystems that require additional intervention to realise the benefits.

Optimise the system lifetime

We'll use a strategy called design for lifetime to optimise the preliminary solution at the subsystem and components levels.

***Base task*:** Communicate your Project Group's optimised preliminary solution, indicating the features that arose from the application of design for lifetime. You choose the format (side-by-side comparison of preliminary solutions, description, etc.).

Activity

Determine the optimal lifetime and end-of-life strategy for each major component in your preliminary solution. As an example, consider the major components of a multifunction device (combination printer, copier, scanner, etc.). The print materials (e.g., toner and cartridge) have optimal useful lifetimes that range from 6 month (the minimum user expectation) to 10 years (the expected useful lifetime of the device). Their optimal end-of-life strategy is probably remanufacture, especially for components that have 6-month useful lifetimes, because they are products of consumption. The hardware (e.g., electronics, mechanisms, structure, and shell) have optimal useful lifetimes of 10 years (the expected useful lifetime of the device). Their optimal end-of-life strategy is probably reuse because, at end-of-life, nearly all parts operate like the they did when the device was new.

Identify and apply at least one appropriate design-for-lifetime feature for each major component in your preliminary solution. Consider the *Design for product lifetime* learning resource.

***Extension*:** Explain how a single optimisation results in improvements in the lifetime of multiple subsystems or components.

Conclusion

We've now concluded our processes for the Preliminary Design phase. We developed our conceptual solution into our preliminary solution by optimising at the system level and designing at the subsystem level. We've now reached the end of our design process for OENG1118.