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Embodiment

> Embodiment is the design task that assigns form to function.

What is (an) embodiment?

“Embodiment” is a word that can be both a verb and a noun.

When used as a noun, “an embodiment” is a term used to represent a physical principle or general class of technology, the behaviours of which can be used to provide one or more functions in a given situation - that is, it's a principle or technology that satisfies FRs as well as any non-functional requirements that pertain[1].

When used as a verb, “to embody” is a term used to name the activity of finding embodiments (nouns) for given functions in given situations.

Functions are denoted by verbs (*“to heat…”* or *“to carry…”*), whereas embodiments are generally denoted by nouns (“*radiant heater*,” “*handbag*,” “*convection*,” or “*shipping container*”).

Thus, we may define *embodiment design* as the step of moving from function to behaviour, which makes it a part of concept design.

See the Examples section below for instances of embodiments.

Why do we embody functions?

Embodiment is a critical creative element of a design process. All design activities before embodiment treat function. Embodiment is the activity that begins to translate functional representations of design interventions into structural ones by way of behaviour. That is, embodiment maps function to behaviour.

When do we perform embodiment?

Embodiment is the first step in developing an implementable design intervention in that it results in a behavioural description of the set of suitable design interventions. Any concrete design intervention that meets the behavioural specifications given by an embodiment is a candidate design solution.

Therefore, embodiment is performed after all the functional specifications are complete for a given design situation.

How do we embody functions?

Embodiment is about searching for physical principles and technologies that can provide needed functions. While it is possible to search for such principles and technologies, it is far faster to already know about principles and technologies. This is why good engineering designers keep up with the latest R&D developments, new technologies, and cutting edge scientific research; it is from that work that an engineering designer will draw embodiments. This is why many engineers are interested in both science and new technologies, "gadgets," and other inventions. Having at-hand knowledge of diverse technologies and principles allows one to think of more potential embodiments.

Another way to find embodiments is to build on an embodiment you already know or have found, and then consider how that embodiment could be changed without changing the required functions that it provides. One technique to do this is to change physical phenomena of some characteristic of a known solution.

Another, slightly more complicated way, involves:

1. Find as many occurrences as you can of the initial embodiment in *existing* products.
2. Study those products to discover what other ancillary functions they provide.
3. Now find as many products that provide those ancillary functions.
4. Study those products, looking for products that provide the function you need as an ancillary function.
5. Consider those embodiments as possible embodiments for your design.

Constraints are very important in embodiment design. A given embodiment (i.e., a given principle or technology) will only work best, if at all, within certain situations. Those situations can be described with constraints; that is, the constraints bound the situation and distinguish it from other situations. This will be made clear in the examples below. Thus, to succeed in embodiment design, one needs to know the functions to be provided *and* the constraints on those functions.

The creative act of embodiment cannot be explained because no one has (yet) devised a theory that reliably lets people "be creative." However, there are many methods that have been devised that *may* help you find an embodiment. While no one creativity method is guaranteed to work in a given case, the odds are high that one method or another will work in virtually any circumstance. See creativity method for more information.

The result of an embodiment activity is a principle or technology that can provide the needed function. An embodiment is described with the following:

- a short (2-5 word) description of the principle or technology,
- a stylized sketch of the principle of technology as it pertains to the design problem you are trying to solve, and
- and reasonable background information (research) that explains the principle or technology in general terms, to justify its selection as a possible embodiment of specific function(s) in a specific situation. This ought to also clearly identify any creativity method used to develop the embodiment.

Note that the first two items (the short verbal description and the sketch) are used in morphological charts.

However

Since any system typically contributes multiple functions in a situation, it can be difficult to decide which embodiments are most appropriate in a given case. One seeks embodiments *before* one has enough information available to precisely rank candidate solutions. One must therefore remember that any ranking of potential embodiments must allow for this ambiguity. In other words, you may not be able to tell good embodiments from bad ones. That's okay.

In cases like this, remember to focus on *purpose*. Each system may contribute to multiple functions, but there will be *one* key function - which is the purpose of the system's existence - that is most important. Any candidate embodiment *must* provide that purpose.

If you find that two or more functions of a system are entirely disjoint (e.g., braking a vehicle and steering that vehicle), then it is unlikely that you will find single embodiments that can provide both functions. This is usually an indication that you partitioned your systems to coarsely; that is, you should have broken your systems into finer subsystems before trying to embody them. If this happens, stop the embodiment process, return to system design, and sort out what actual subsystems you need.

Examples

Convert Rotational Motion to Linear Motion

Say you need a system the function of which is *to convert rotational motion into linear motion*.

Two possible embodiments are a rack and pinion and a slider-crank mechanism. Simply identifying these mechanisms is not a complete design: we have not identified dimensions, materials, or other physical characteristics at all.

Which of the two embodiments we choose will depend on constraints and non-functional requirements. A rack and pinion is often used for high precision movement where applied forces are generally low. Slider-crank mechanisms are often used where there are very high forces but precise movement is not very important.

By choosing, say, a slider-crank, we *exclude* all other embodiments, including rack and pinion mechanisms, but we have not actually defined the size, shape, material, or any other characteristics of a slider-crank - we've only identified a class of device or technology.

Transfer Heat

Say you need to *vent heat without converting the energy into an intermediate form*. In the most general case, there are three possible embodiments for this: radiation, conduction, and convection. From each of these embodiments can be inferred whole classes of technologies that implement them.

In this case, we see that embodiment can proceed in stages. First, we identify which of the principles of radiation, conduction, or convection is the one that will suit our problem. We can then *further* embody that principle by examining all the different technologies that can be used for the principle we chose.

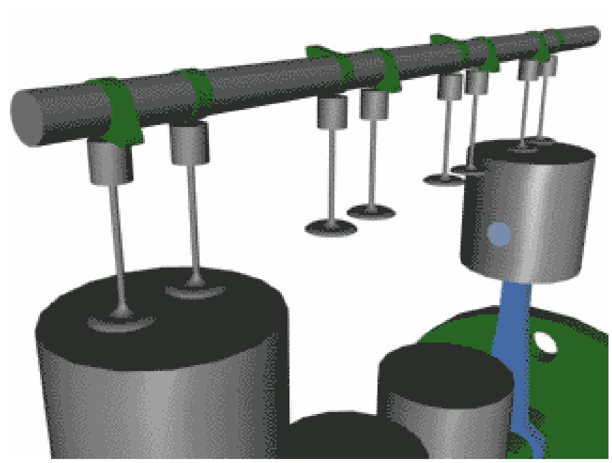
Of particular importance will be the constraints associated with the function in the given situation. The amount of heat to be vented, the expected temperature ranges available or required, the variability of the heat to be vented, and the thermal coefficients of nearby external objects (i.e., other things in the context) will all play a role in identifying appropriate embodiments. Some technologies will only work well with relatively small temperature differences; others may only work well under cyclical heating/cooling regimes.

If, on the other hand, we could remove the constraint of no intermediate forms, then we might also consider other solutions such as chemical processes - heat can be stored in chemicals which, when mixed with other chemicals, release the heat.

> ***Exercise for the reader:*** How many examples of such intermediate heat storage systems can you think of?

Novel rocket propulsion

Fig. 1: Valves in a typical internal combustion engine.



You are tasked with looking for a new kind of rocket propulsion.

A key feature of conventional rockets is that they apply a nearly point force from the “back” of the rocket, propelling it forward.

Ask yourself, what other products involve forces applied from one end of a relatively long, thin shape?

If you search broadly enough, you might discover that valves in internal combustion engines work that way. Notice how the valve is repeatedly pushed down by the camshaft. (See the image to the left.) If the valve were not constrained by a spring to return back to its original position, the push from the camshaft would just send the valve flying away (into the combustion chamber).

Now consider how one may find a way to give a series of successive, cyclical pushes to a space vehicle, from behind, to push it forward. It would have to be a rather large force to move something as large as a space-vehicle. Of course, there are no camshafts in space, but you're searching for something that can be behind the space vehicle proper, that, when activated, pushes the vehicle forward.

There are a variety of solutions that have already been thought of - and remain surprisingly possible.

One solution is to have a ground-based laser (acting as the camshaft), shining laser light onto a large reflective surface at the back of the vehicle (acting as the top of the valve). The laser light exerts pressure, because `E=mc2`, and pushes the vehicle.

Another possibility is to detonate explosives behind the ship; the explosion pushes on a large plate at the back of the ship, driving it forward. Indeed, this is exactly the principle of a concept space vehicle called Orion.

If we relax the constraint of pushing the ship from the rear, we can think of mechanisms that “pull” it from the front. Such a solution would keep the ship in tension (rather than the compressive forces arising from pushing from the rear); this would eliminate the concern of buckling in structural elements. On the other hand, pulling the ship will require a substantive redesign of the structure which could increase the risk of other types of failure.

> ***Exercise for the reader:*** What if the engine were a long tube running down the length of the ship and that acted like a particle accelerator?

Somewhere to Sit

Say you need a system that provides the function of allowing people to sit down.

Chairs are one embodiment. A kitchen counter can also provide that function, but it requires one to hop up on it.

Did you consider *who* these people are who will sit down? Does that affect your thinking about embodiments?

> ***Exercise for the reader:*** How many other embodiments can you think of?

creativity, method, concept, systems, function, behaviour, process

1)
Note that different authors will use different definitions of this term, depending on the overall framework they're working in. Consider, for instance, the definition used by Pahl and Beitz in their classic text.

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