Many Costs and One Objective

How do humans make decisions? The answer is not always pleasant. Humans often make decisions irrationally, based on emotions, unaware of faulty instincts, and overestimating the probability of rare events (Kahneman 2011; Kahneman and Tversky 1979; Tversky and Kahneman 1992). On the other hand, it is perhaps wrong to expect humans to act like machines, always optimizing based on rational models. In fact, philosophers such as Baruch Spinoza (1632-1677) and Arne Næss (1912-2009) have argued that the role of emotions is crucial and often undervalued when we talk about "rational" decisions.

How do engineers, developers, and society make structural design decisions? Usually based on formulas in building codes and material standards. Those formulas are handed down by code committees and contain prescribed safety coefficients that are applied to seemingly deterministic load and resistances values. The safety coefficients are usually calibrated to some target reliability index, β, typically above β=3, which implies a failure probability below $10^{-2.87}$, but rarely above β=4, which implies a $10^{-4.5}$ failure probability. What those probabilities imply may be unclear but they are meant to match currently accepted practice. Experienced engineers often add important cost-benefit considerations to the design process, but rarely using optimization algorithms and explicit models. When researchers do that they find risk averse or even risk seeking designs compared with the rational optimum (Cha and Ellingwood 2012; Mahsuli and Haukaas 2018).

But what is the "rationally optimal design?" It is the design that maximizes the total expected utility, including all costs and benefits, of the facility over its lifetime from material extraction to demolition or deconstruction (von Neumann and Morgenstern 1944). For example a hospital should be safer than a one-car garage because the failure costs are different. The mantra of expected utility theory is behind much of the material posted on this website but it is not universally accepted in structural design, for two reasons:

1. Expected utility theory requires models for *many costs and benefits*. This is a big effort that involves probabilistic modelling. Environmental impacts, cost of injuries, and other *intangible costs* must be quantified. This is a rational approach but still awkward for many humans.
2. All concerns must be *translated into a unified measure of utility*, i.e. euros or dollars. The weight of a particular concern is often debatable. In fact, the *utility of a facility may vary by stakeholder*; a developer may be concerned primarily with profit, while members of the general society may be more concerned about economic growth or environmental damage.

Among researchers who pursue the rational optimization approach there is little debate about Item 1. Any optimization analysis requires one or more objectives and Item 1 addresses the modelling of those objectives. Item 2 is sometimes circumvented by the use of multi-objective optimization algorithms, avoiding a summation of concerns into one utility. However, this is not a rational solution; at some point the different concerns must be weighed to arrive at a unique design decision. To understand this, imagine you have to choose between two jobs, one with $70,000 salary and 8 weeks of vacation per year, the other with $110,000 salary and 2 weeks of vacation. Unless you leave the decision to a multi-objective optimization algorithm you must quantify how much vacation time is worth to you.

Figure 1 addresses Item 1 and shows a matrix of costs and benefits that accumulate over the lifecycle of a building. It is seen that each phase of the lifecycle, from planning to demolition or deconstruction, is associated with economic, environmental, and social impacts. Only impacts that vary with the design variables need to be modelled. For example, only the impacts from past and future construction that are affected by the design of our facility need be included.

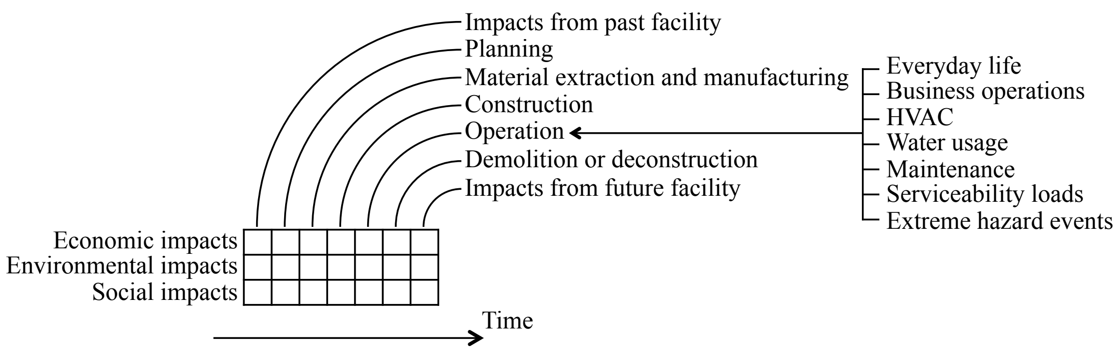

Figure 1: Phases in the lifecycle of a building.

Required Impact Models

(Incomplete…)

- **Economic impacts**
  - Invoices issued and paid
  - Gross domestic product
  - Number of people employed
  - Interest rates
  - Human injuries and deaths
  - Functionality and downtime
- **Environmental impacts**
  - CO2 emissions
  - Global warming potential
  - Energy usage
  - Water usage
  - Pollution, poison, and human health
- **Social impacts**
  - Aestethics
  - User experience
  - Homelessness
  - Human injuries and deaths

Decision Variables

(Incomplete…)

- Material type
- Structural topography
- Member shapes
- Member sizes

Decision Perspectives

(Incomplete…)

- Society
- Government
- Owner, developer