Design at the faculty of Technology, Policy and Management

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Abstract

Research at the faculty of Technology, Policy and Management (TPM) of Delft University of Technology focuses on large scale socio-technical systems, such as infrastructures for transport, energy and telecommunication. These systems are not designed and then constructed according to plan, but develop over a long period of time as the result of countless changes. Nonetheless, most of these changes have been purposefully designed. The characterization of three types of design—system design, decision process design, and institutional design—put forward in this paper is meant to sketch with a broad brush the variety of design problems that must be addressed in the context of socio-technical system development. This will hopefully give the reader a fair idea of design as it is professed at TPM.

1. Introduction

A major problem that I sense when writing about design for an audience that largely consists of engineers is that they tend to know much better than I do how systems in their particular technical domain are conceived, specified in detail, and eventually constructed. Moreover, every technical domain has its own engineering vocabulary. This in itself is not a bad thing, but the trained mind tends to reject otherwise perfectly acceptable views when they are phrased using one's own pet words in a different context. Therefore, please do not to halt at the first point where I give a meaning to a term that seems to be at odds with your own professional knowledge! The objective of this essay is not to propagate a particular truth about design, but to highlight similarities and differences of three types of design that have emerged from a decade of scientific inquiry into socio-technical systems conducted at the faculty of TPM: system design, decision process design, and institutional design.

To achieve this objective, I have chosen a starkly reduced vocabulary on design, which I will define shortly. While looking for examples, I have opted for stylized fictitious design cases because these provide the most didactical illustrations. The cases have in common that they all address the problem of reducing the CO_2 emission by traffic, and will be presented in separate sections. I will start with a sketch of the types of *system* that engineers from various technical disciplines might design to solve this problem. I then use the same approach to describe alternative designs of a *decision process* that, when executed, should lead to a policy to reduce CO_2 emission by traffic. Next, I outline different designs of an *institution* that would resolve the CO_2 issue. The three characterizations give rise to the question to what extent systems, decision processes and institutions can be designed and how these designs are interrelated. For lack of an adequate answer, I conclude by referring for each type of design to a number of representative projects in the research programs of the faculty of TPM.

2. A conceptual model of design

The conceptual model of design used in this essay is based on the rational actor paradigm (RAP, see [1]0). It is crude but very generic. Design is viewed as a purposeful activity that involves various *actors*: individuals, teams of people, or larger organizations. These actors (inter)act in what I shall broadly refer to as a *design context*. Assuming that actors can think rationally and act purposefully, three main actor *roles* can be discerned:

- *Client*: This actor has a *client problem* in the sense that he[1] considers the present state of the world around him as unsatisfactory, or likely to become unsatisfactory in the foreseeable future.
- *Designer*: This actor translates the client problem into a *design problem formulation*: an abstract description of the client problem in terms of means and ends. He then uses what knowledge he has at his disposal to make a *design*: a representation of an *artifact* and of the *environment* in which this artifact will be realized. This artifact is such that, when realized, the client problem will be solved.
- *Realizer*: This actor executes the design by making the artifact it represents real. He does this by taking actions prompted by the design.

The reason to distinguish between actors and roles is that in some design contexts an actor may assume more than one role.

The word 'design' is a noun as well as a verb. Design-as-verb denotes a purposeful intellectual activity that produces a design-as-noun. Design-as-noun denotes a representation of an artifact that provides sufficient guidance for the realization of this artifact. The design activities and realization activities are considered to be separated:

design activities → design → realization activities → artifact

The design activities include communication between designer and client, acquisition of knowledge about the environment in which the artifact is to function, design problem formulation, generation of alternative (partial) representations of the artifact, evaluation of alternative designs, and eventually selection of the design that is to be realized. The realization activities include modification of the environment (to better accommodate the artifact), acquisition of resources, production/construction of components of the artifact, and eventually delivery to the client.

The design (= representation of the artifact) as separation between design activities and realization activities is what distinguishes *designing* an artifact from *developing* an artifact. The design allows an *ex ante* assessment of the changes the artifact will cause in the real world, and allows the designer (and the client and the realizer as well) to judge the merits of alternative designs.

The design and realization of an artifact in response to the client problem can be viewed as a linear transformation process:

client problem (CP) → design problem formulation (DPF) → design (D) → artifact (A)

The design problem formulation is produced by the designer, albeit in interaction with the client. It is the designer's professional skill to transform the client problem (= dissatisfaction with a (future) world state) into a precise definition of goals and constraints (operationalized in terms of performance indicator/target value pairs) and available means (operationalized as a set of design variables/feasible option range pairs). A complete design problem formulation also defines a *test*: a procedure that, when executed, produces the answer to the question "how well will the artifact that is specified by this design solve the client problem when it is realized?".

The designer then proceeds by generating and testing alternative designs (selecting a single option for each design variable and estimating whether the chosen combination will affect the performance indicators in such a way that their respective target values are achieved), until he has found a design that suffices for the client (i.e., passes the test) and satisfies the designer.

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[1] Without intending any gender bias, I will refer to all actors in the masculine form.

Looking more closely at the linear transformation process CP → DPF → D → A, several iteration loops can be identified in this sequence:

- the problem analysis loop CP ↔ DPF in which client and designer interact
- the solution finding loop DPF ↔ D, which is the domain of the designer
- the implementation loop D ↔ A in which designer and realizer interact
- the evaluation loop A ↔ CP in which the client discovers that he has a new problem

Although these loops are often used to model the dynamics of a design process, they hide the underlying transformations that actually proceed sequentially in time:

$CP_1 \rightarrow DPF_1 \rightarrow CP_2 \rightarrow DPF_2 \rightarrow D_1 \rightarrow DPF_3 \rightarrow D_2 \rightarrow A_1 \rightarrow CP_3 \rightarrow DPF_4 \rightarrow \ldots$

This representation of a design process as a sequence of transformations allows researchers to more precisely identify different 'versions' of client problems, design problem formulations, designs and artifacts, and to individually address and study each of the transformations '→'.

The outcomes of the two transformations CP → DPF and DPF → D are largely determined by the designer's knowledge and will therefore be biased by what in the literature on social construction of technology is called the designer's *regime* [2]. A flawed CP → DPF transformation is known as an 'error of the third kind' or 'type III error', because it leads the designer to look for solutions for the wrong problem [3]. In the transformation D → A, the realizer may deviate from the design due to misinterpretation of D or in response do changing circumstances in the context of A.

In the examples that follow in the next three sections, I will create variety in designs by assuming what may seem to be caricatures of regimes. Interesting though they may be, I will not dwell on type III errors, iteration loops, or aberrations that may occur during the realization of artifacts, because this would distract from the principal purpose of this essay, which is merely to illustrate the three types of design that are most relevant to socio-technical systems.

3. System design

In the first fictitious design case, the client is some governmental agency that wishes to significantly reduce the CO_2 emission by traffic. For this example, let's say the ambition level is a reduction of at least 30% on a national scale. The client does not know how to achieve this goal, and therefore has a problem. One can easily imagine that, when asked to deal with this problem, designers from different regimes would make different interpretations of the problem, which would result in different design trajectories:

- An electrical engineer might consider replacing the combustion engine in cars by an electromotor, powered by batteries that would be charged with 'green' electricity, or by fuel cells (either non-carbon or with a much higher fuel efficiency than current engines). The transport system would otherwise remain unchanged; only the fueling stations would need modification.
- An control engineer might propose a road pricing system that would track the movements of vehicles and charge their owners for using the road network. Tariff differentiation in space and time would allow the national government to discourage use by certain user groups (e.g., high-emission vehicles) or during certain periods of the day (e.g., to reduce congestion). Both measures would lead to a lower CO_2 emission.
- A civil engineer might think of an even more radical modification of the transport infrastructure, changing from a system based on fuel-powered automobiles with free access and movement on an open network of roads to a public transport system based on electrically powered vehicles such as (metro) trains, supplemented with a highly regulated taxi system to cover the 'last mile'.

In all cases, the system engineers would not only consider technical feasibility and CO_2 emission levels, but also a range of other system performance indicators, including transport service level, safety, and of course cost. Their designs would also include a 'migration path' describing how the transition from the present system to the new system could be made over time. The national government could complement the system design with tax policies to balance costs and revenues.

Obviously, these sketches do no justice to the complexity of the design problems, but they do illustrate these characteristics of 'system design':

- The artifact is 'tangible' in the sense that it involves physical objects such as vehicles, batteries, engines, RFID transponders and computer networks.
- The designs will typically consist of technical specifications, drawings and models.
- The designs are based on al large set of assumptions with respect to the artifact and the environment in which it is to function. These assumptions are predominantly technological, derived from the natural sciences; much less from the social sciences, with the exception of economics.
- These same assumptions are the basis for the (computer) models that perform the test that is defined in the design problem formulation to verify whether the designed artifact solves the client problem when it is realized.

4. Decision process design

The second fictitious design case revolves around the same client: some national government agency wishing to reduce CO_2 emissions of traffic by 30%. But now the design problem formulation is quite different. The artifact to be designed is not a traffic system that, when realized, will deliver the transport service capacity of the same level as the present situation while emitting 30% less CO_2, but a *decision process* that, when realized, will result in a transport policy that will achieve the goals and also have the support of all relevant stakeholders (industry, citizens, etc.).

To illustrate that the concepts from §2 also apply to this kind of design problem, I will sketch four different design trajectories that lead to very different decision process designs. These design trajectories are inspired on the four 'calculated rationalities' described in [4]: bounded rationality, contextual rationality, game rationality and procedural rationality. Although these rationalities are not true 'regimes' as defined in [2], they do reflect particular schools of thought in the policy literature.

- When taking bounded rationality as the starting point, the designer would define a decision process that takes a 'satisficing' approach [5] to the CO_2 reduction problem. This would involve a simplification of the problem formulation to such an extent that rational optimization using available knowledge becomes possible. The design would typically describe the decision process as consisting of three phases: an 'intelligence' phase in which goals and constraints would be defined, a 'design' phase in which various alternative system designs similar to those outlined in the previous section would be developed by system engineers, and a 'choice' phase where the alternative systems would be evaluated on the basis of a limited set of criteria for which impact assessment methods are available, such as for example the transport service level (% of demand met by the system) and cost effectiveness (kg CO_2 $year^{-1}$ $€^{-1}$). Eventually, the system with the highest cost effectiveness that would meet a pre-defined standard for the transport service level of, say, 90% would be selected.

- The 'regime' of contextual rationality would lead the designer to define a decision process that would let the actual circumstances define the decision making agenda. The national government agency would respond to political pressures of the moment, and the decision would 'happen' as soon as a 'window of opportunity'—a propitious configuration of problems (not only the CO_2 problem, but also any other business at hand, such as high oil prices, badly congested highways, and a referendum on the EU constitution coming up), feasible solutions and political will—would open [6].
- A decision process design based on game rationality would define incentives in such a way that the maximum overall utility is achieved when all actors strive to maximize their individual interests. Such a design could, for example, involve a policy based on the market value (in € kg^{-1}) of international CO_2 emission rights. Using this figure, the economic value of 30% of the present total CO_2 emission by traffic would be established and the national government agency would use this budget to put out a tender for CO_2 emission reduction schemes (positive incentive). To urge the industry to actively develop such schemes, the national government agency would use the threat of a CO_2 tax on all carbon-based fuels (negative incentive), the revenues of which the government would use to buy international emission rights.
- The 'regime' of procedural rationality would direct the decision process designer to develop decision making procedures and conventions that are most compatible with tradition. This could of course be something very close to the 'usual politics' of the design based on contextual rationality, but one can also envision a decision process design that copies the approach taken to reduce waste from packaging [7], [8] to strike a delicate balance between protection of stakeholder interests.

Like in the previous example, these sketches are very 'broad brush', but they do illustrate these characteristics of 'decision process design':

- The artifact is 'intangible' in the sense that it is a process of social interaction. A decision process does not involve the kind of physical components that together constitute a technical system.
- The designs typically consists of 'rules' that actors should observe in the course of the decision process. These rules are designed to guide the actors participating in this process towards consensus on the policy issue that is to be decided upon.
- The designs are based on a large set of assumptions with respect to actor behavior in response to these rules. These assumptions are predominantly behavioral, derived from the social sciences, notably those addressing aspects of decision making and rationality (see [1]).
- The test that should be part of in the design problem formulation is usually implicit: the design meets the test when the rules it defines are accepted by all the actors involved.

5. Institutional design

Institutions are defined in [9] as "the rules of the game in a society or, more formally, the humanly devised constraints that shape human interaction. In consequence, they structure incentives in human exchange, whether political, social, or economic." (p. 3). By this definition, marriage is an institution. Although the 'rules of the game' associated with marriage may change from culture to culture, they evidently shape human interaction. Whole kingdoms have been joined through marriage, causing great shifts in wealth and power more easily than war, and making the relation between princes and princesses an object of strategic planning. Likewise, the rules for succession have affected (and still do affect) both social and political behavior. Constitutional monarchies, people's republics and all other forms of government are institutions, as they define how states are ruled.

By looking for the 'rules of the game' in a society, one can identify a variety of institutions: legal courts, systems for education, health care, registration of property rights, taxes, trade, industry, etcetera. Although there may be no clear hierarchy for institutions, social and economic institutions will always be constrained to some extent by political and governmental institutions.

Institutions are ‘formal’ insofar as the ‘rules of the game’ have been codified in laws and regulations. Laws and regulations can be changed, which suggests that institutions can be designed and realized. For the formal aspect of an institution, this may be true: rules and regulations can be developed ‘on paper’ and are realized when they have been affirmed by the authorities, such as the parliament for legislation. But the realization of the informal aspect of an institution is achieved only when patterns of social behavior have changed in the intended way.

To illustrate the concept of institutional design, I will again use the fictitious case of a national government that looks for a way to regulate traffic in such a way that CO_2 emission will be reduced. As in the two preceding sections, I will sketch different design trajectories that correspond to particular problem conceptions. This time, the variety is not the result of differences in technological regime (the car with combustion engine remains the principal mode of transport) or decision rationality (I disregard the policy process), but of different political philosophies that I have associated rather casually with three forms of social structures: markets, hierarchies and networks [10].

- A designer inclined to liberal capitalism would choose to design a market. To solve the CO_2 emissions, the government could issue tradable emission rights up to the maximum acceptable level, and the ‘invisible hand’ of the mechanism of supply and demand would ensure maximization of the overall utility of the traffic system. The market would automatically provide strong incentives for the development of low-emission vehicles, but unfortunately also for finding ways to circumvent the system.
- A designer inclined to centralistic communism would prefer to design a hierarchy to regulate the use of automobiles. Both cars and roads would be public property. The demand for transport would be investigated by region, and based on this demand, resources would be allocated by authorities on different levels down the hierarchy. The plans for production and allocation of resources would be optimized within the constraints of available technology, cost-benefit assessments, and of course the CO_2 emission limits.
- A designer inclined to idealistic socialism would design a network for voluntary resource sharing amongst individuals. The location, itinerary and seat availability of privately owned and operated cars would be made public to facilitate car pooling, there would be guidelines for ‘proper conduct’ when signaling a vehicle to catch a ride, and there would be incentives for sharing, such as dedicated highway lanes for cars with more than one passenger.

Obviously, the outline examples are caricatures, but they serve to illustrate these characteristics of ‘institutional design’:

- Here, too, the artifact is ‘intangible’ and the design consists of rules, but there is a marked difference with a decision process. The design of an institution is realized when the ‘rules of the game’ that constitute the institution have been internalized by society to such an extent that they indeed give a different shape to human interaction. The realization of the artifact is this ‘internalization’, not the changes in human interaction it causes.
- Like decision process designs, institutional designs are based on assumptions with respect to actor behavior in response to these rules, but where decision process designs are highly pragmatic and aim for closure on a particular decision within a relatively short time span (months or years), institutional designs are strongly influenced by ideology and aim for changes in social interaction that last for generations.

- The assumptions that underlie institutional designs are based on theories from social science that address behavioral and cultural aspects of collective action (see [10], [11]).
- Although certain design principles for the design of institutions have been formulated [11], the test that should be part of in the design problem formulation is mostly conceptual and argumentative. Compatibility with existing institutions is difficult to test, but social simulation and gaming are developed for this purpose [12], [13].

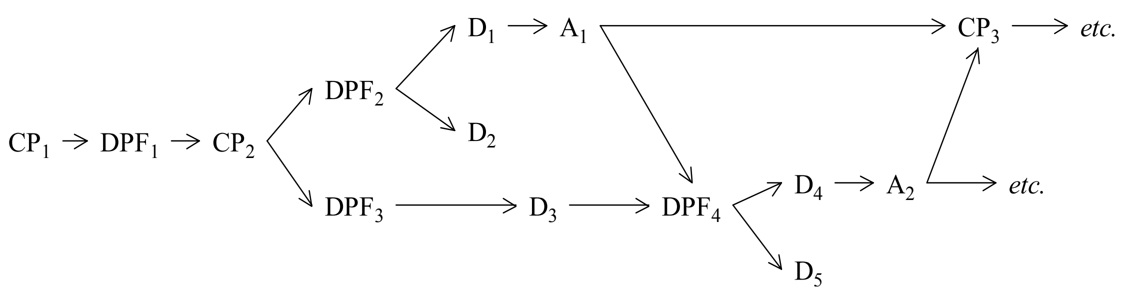
In summary, despite the fact that institutions seem to fit the generic design model of §2, institutions are difficult to design as true artifacts, because they must be closely aligned to existing institutions. The model of tradable emission rights fits nicely with the present liberalization trend in western economies. The central resource allocation would require a large and powerful bureaucracy to be already in place. The car sharing model would only fit in a society in which social networks are already strong and 'helping your neighbor' is a matter of course. In this context, I find it significant that car pooling presently accounts for some 15% of all work-related trips in the United States [14].

6. Conclusion

When the same conceptual model is applied to different empirical phenomena, one is more likely to notice similarities than differences. One observation is that decision process design and institutional design differ less from each other than from (technical) system design—a difference that can easily be explained by the different sources of scientific knowledge they are based upon. One could even argue that there is no fundamental difference between the former two types of design, as the artifacts can both be seen as 'codes of conduct'.

A more intriguing observation is that, whether tangible or intangible, all artifacts have in common that they are 'constructions' that enable or support 'processes'. Artifacts are designed to structure flows in such a way that the result satisfies the client. Fuel cells convert an input stream of, for example, methanol into output streams of electricity, CO_2 and water. Road networks enable traffic flows. A process standard, once it has been ratified, provides the structure for the dynamic flow of stakeholder negotiation and policy decision making. In this respect, there is no fundamental difference between tangible and intangible artifacts: The micro-electronic devices used in road pricing systems enable a wireless data communication process in much the same way the social 'rules of the game' for car pooling enable an exchange between driver and co-travelers that is both satisfying and convenient.

Most of the designs that I have outlined show that design of tangible artifacts (technical systems, such as the information and communication systems) and the design of intangible artifacts (social systems, such as decision processes and regulations) are interlaced in a larger process of design. A more elaborate analysis of this process as a succession of design transformations would produce not a linear sequence, but more likely a directed graph in which many paths split and join later on as different design sub-problems—some dealing with technical artifacts, some with social artifacts—are concurrently formulated and re-formulated by different (although possibly overlapping) multi-actor design teams over time:



Although the examples I have given are fictitious, similar design problems related to infrastructures for transport, energy, and telecommunication are actual objects of study in the research programs of the faculty of TPM. The following selection of issues may give an idea of their aim and scope:

- System design: automated container terminals [15], production clusters in the chemical industry [16], e-service architectures for public and private sector [17]
- Decision process design: environmental policy making [7], [8], urban planning [18], water management [19]
- Institutional design: regulation of infrastructure for public transport [20], natural gas [21], and electricity [22]

The design problems that are investigated only rarely have a single client, a single designer and a single realizer. They are multi-actor problems for which not only physical or facilitating structures have to be designed, but also regulations and/or regulative processes. The processes of system design, decision process design and institutional design are interlinked, which makes methods and tools for the design of design processes a challenging area of research. The duality of *structure* and *flow* that can be discerned at multiple system levels along several dimensions (physical, behavioral, informational, organizational, ...) lies at the very heart of the complexity of socio-technical systems. Researchers at the faculty of TPM aim to gain a better understanding of the constraints this duality imposes and the opportunities it offers.

Fig. 1. Physical components of a socio-technical system for road pricing (source: Toll Collect, Germany).

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