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ASSISTING DESIGNERS IN EVALUATING PROPOSED SOLUTIONS THROUGHOUT THE DESIGN PROCESS

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Abstract

Designing consists in translating needs into a product definition. The research work presented in this paper leans on the assumption that considers this process as a co evolution of both needs and solution, between which designers perform alternatively propositions of solutions and evaluation of those solutions. In this sense, the final purpose of this work is to provide designers with a tool that aims at supporting the evaluation of the proposed solutions in an integrated design context. To achieve this, the authors performed a study of existing design methods and tools, and illustrated it on an industrial case study. A model for the evaluation criteria used throughout the design process is proposed and discussed. This model was validated by a protocol study based on a well-established design experiment.

Keywords: evaluation of design, decision-based design

1. Introduction

Nowadays, from an overall point of view engineering design can be considered as a transformation process, which translates customer needs into a product definition. It is a well widespread opinion within the engineering design research community. This process must take into account every constraint related to each stakeholders of the product life cycle at the earliest phases of the design process. The integrated design approach proposes to achieve this task by integrating those stakeholders into a multidisciplinary design team.

Our research is based on the assumption that an efficient achievement of this process, which means a better product quality, a shorter time and a slower cost, requires on one hand a comprehensive expression of both needs and constraints, and on the other hand an early evaluation of how the designed product meets those needs and constraints. The objective of this paper is a model supporting the evaluation of a current design solution in an integrated design context.

Section 2 is a study of how existing methods, tools and techniques support this dual task, focusing on both their shortcomings and their most relevant features, kept in our research. The third part of the paper then lay down the theoretical foundations on which the model proposed in section 4 is built. The fifth part of finally describes how this model correlates with a real design situation.

2. Methods for the needs expression and its achievement

Several prescriptive design methods are described in literature. They aim at supporting the design process by providing designers with techniques and tools improving their activity. In our survey functional analysis (FA), value analysis (VA) (sometimes called value engineering, or VE) and quality function deployment (QFD) were the most relevant, and their use onto an industrial case study was tested. The Pugh's approach [1] is also presented in this paper, since it is a reference work on evaluation throughout the design process.

2.1. Functional analysis

This method [2] consists in describing a product by the set of the functions it is supposed to fulfil, ("what the product is supposed to do"). These functions, called external functions, can be expressed as a short sentence, the subject of which is the product and the verb describes the required function. A distinction is made between interaction functions, which purpose is to link two interactors through the product, and adaptation functions, which aim at adapting the product to its environment. Let us illustrate this definition onto an industrial example, a bathroom scales. The "graph of interactors" tool identifies and formalises functions for a product life-cycle step. Figure 1 illustrates the use step of a bathroom scales.

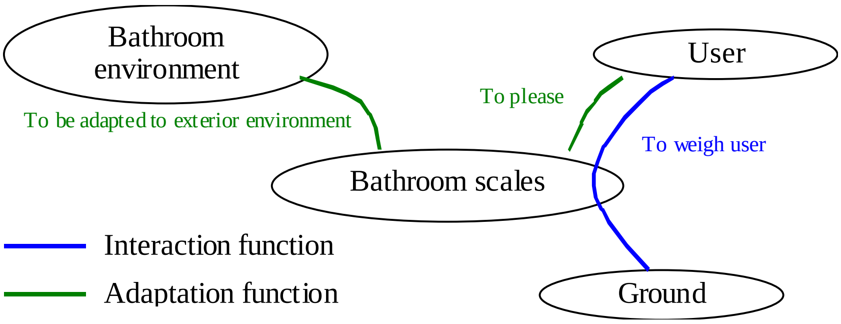

Figure 1. The graph of interactors of the bathroom scales

Table 1. External function and associated criteria

Function	Appreciation Criteria	Level	Flexibility
To weigh	Maximum weight	160kg	Minimum
To weigh	Comfort	Ok for 70% of testers	10 % left if better precision

Table 2. Technical functions and associated criteria

Function	Appreciation Criteria	Level	Flexibility
To acquire	Sensitivity	1 mV. for 1 gram	Minimum
To receive	Plate size	260*260 mm	10 % left if better precision

The required fulfilment of those functions is quantified using appreciation criteria. They are defined as a characteristic used to evaluate the performance expected from the product. Each of them is associated with an expected level of performance and its flexibility. Table 1 gives the example of some appreciation criteria associated with the interaction function "to weigh".

To fulfil those exterior functions, a product is designed using internal (or technical) functions. The FAST (Function Analysis System Technique) can be used to support this task. It is built by developing the required exterior function into technical functions, answering the question "how can be fulfilled this function" when developing to the right, until when elementary technical functions could be fulfilled by products parts. Figure 2 illustrates the FAST of the function "to weigh user".

As appreciation criteria were associated with external functions, internal or technical functions can also be associated with appreciation criteria, as illustrated in table 2. They quantify the level of performance technical functions must reach to fulfil the expected level of external functions. Using the FAST results, the "functional flow blocks diagram" then allows to link functions with the functional features that contribute to their achievement [3].

Based onto the assertion "think function before thinking solution", this method deals with shortcomings presented in part 2.5.

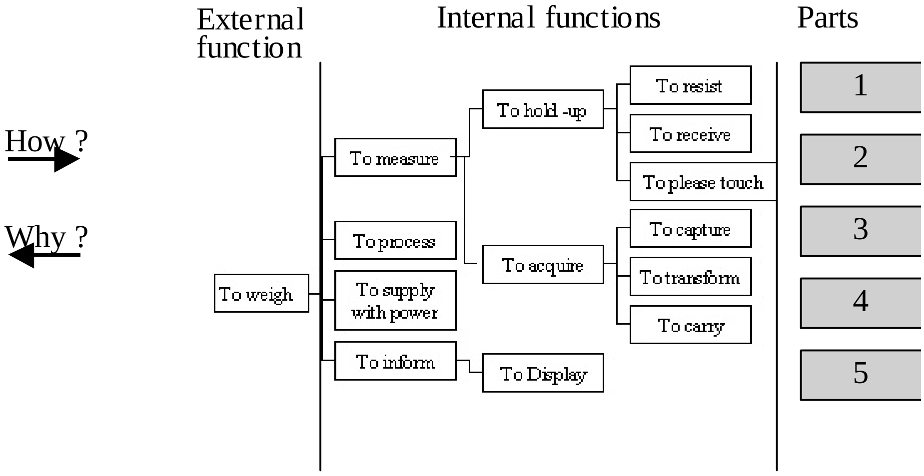

Figure 2. The FAST of the bathroom scales.

2.2. Value analysis

This method is built around the value concept [4]. Value deals with "*the judgement related to the product on the basis of the user's expectations and motivations, expressed by a ratio which grows when, all other things being equal, the satisfaction of the user's need increases and/or that the expenditure related to the product decreases.*"

In this sense, value analysis recommends to make an inventory of the required external functions, and then to balance their relative importance in regard to the concerned stakeholders. The progress of the functional analysis enables to record the technical functions, then the parts and functional features involved in the fulfilment of those required external functions. Knowing the expenditures related to the achievement of the parts and features, a measurement of the product value is thus realised, by comparing the relative balance of the required functions and the expenditures related to their achievement. The present evolution of value analysis is well allotted to the accounting of expenditures related to the manufacturing of the product. The challenge for years to come, due to the sustainable development context, consists in extending this to the management of resources, addressing the whole product life cycle, by taking into account the resources consumptions [4].

2.3. Quality function deployment

Quality function deployment [5] is a method assisting designers in fulfilling customer requirements. Like functional analysis and value analysis, but without using a functional formalism, it supports mappings from customer needs (called "the voice of the customer") to functional features ("part specifications") and even to production characteristics, using several iterations of the so-called "house of quality" (HoQ). The use of this chart-like tool allows to identify and to quantify relationships between parameters and between their relative balances. The different parameters involved in the successive HoQs are not defined or formalised precisely in literature. We can nevertheless use criteria, as defined in functional analysis, to fulfil partially the two firsts HoQs, as illustrated in figure 3.

		weight	working principle	materials	size
To weight	comfort	**v**	.	.	.
	precision	**w**	.	.	.
	maximum weight	**x**	.	.	.
To adapt to the environment	resistance to T°	**y**	.	.	.
	resistance to H	**z**	.	.	.
	weight		v'	w'	x'

	weight	sensor principle	display size	frame shape
working principles	**v**	.	.	.
materials	**w**	.	.	.
size	**x**	.	.	.
weight		v''	w''	x''

Figure 3. The two first HoQs for the bathroom scales

QFD highlights an important aspect: the difficulty to deal simultaneously with a wide set of criteria. Some studies have revealed the difficulties experienced by human mind to achieve such a task, and the necessity to be supported by tools dedicated to the management of decision when criteria are numerous. Multicriteria Decision Aid (MCDA) is a research field in which works are relevant to this purpose [4].

2.4. Total Design

S. Pugh [1] proposed a method to support total design of products systems, "total" meaning taking into account every steps of the product development process. In this approach he advises to build up a "product design specification" (PDS) that should contain elements from 32 different aspects. This PDS is then the frame within which the other steps of the design process should fit, as illustrated in Figure 4. According to this scheme, the PDS evolves progressively during the design process, following the achievement of the successive but iterative steps of the product development process.

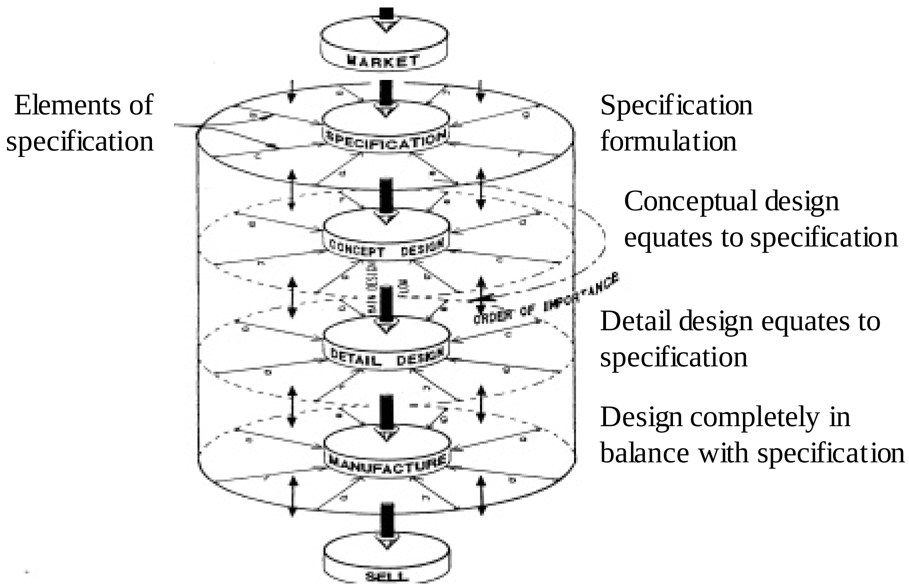

Figure 4. The design process as described in "Total Design" [1]

2.5. Conclusion

Functional analysis, carried out in association with Value analysis, is a successful way to on one hand express and formalise the needs the product to design is supposed to fulfil, and on the other hand to support the achievement of this needs passing through the use of technical functions. QFD is a powerful method to identify and to formalise the interdependencies linking the different aspects raised during the design process, categorized from customer requirements to part parameters and production characteristics. The use of the methods, tools and techniques briefly described above on an industrial case study allowed us to draw some conclusions: they are convenient to be used for analysing statically an existing product, or a product under development. But they are difficult to be used for designing dynamically a product starting from requirements. This difficulty can be explained in regard to the actual progress followed by designers during the design process. Indeed a linear and sequential progress, from requirements to functions then to product, as depicted in the methods above, seems to be in contradiction with the observed design behaviours. Section 3 gives a more relevant progress model, according to experienced behaviours.

Nevertheless several concepts and features are very interesting for our purpose. First the value concept, as defined according to value analysis norms, seems enable to take into account the comprehensive performance of a product, including social, environmental and economical aspects as well as technical or functional ones by addressing in parallel functional features, (i.e. the actions expected from the product), and expenditures, or resources consumptions related to its life cycle [4]. Then the criterion concept, which aims at quantifying the achievement of a function in functional analysis, can be kept as a measurement index for both functional and resources aspects. Section 4 describes how the criterion concept is used to build a model aiming to support the evaluation process.

3. Evaluation of the design process

The methods described above, or other research works [6] describe the design process as a set of steps dealing successively with functional concepts, architectures or principles and physical specifications (Figure 5).

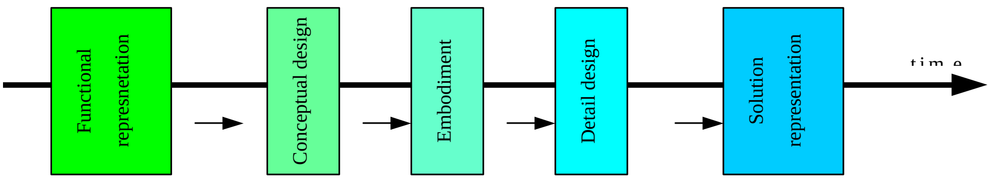

Figure 5. The sequential model of the design process (after [6])

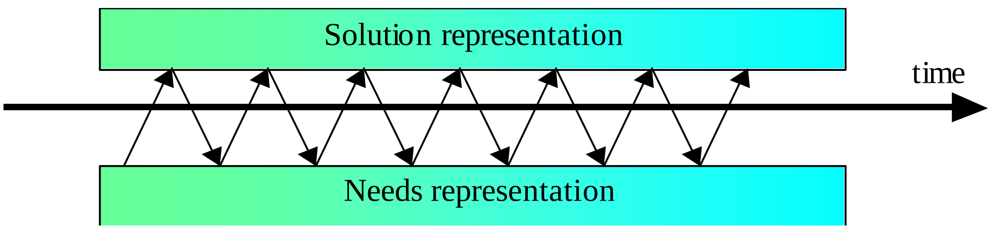

Figure 6. The co-evolution model of the design process

Other works [7] suggest that the design process passes through a set of iterations (a zigzagging) between the needs representation and the product representation, as illustrated in figure 6.

Other approaches correlate positively with this model. Those descriptive approaches were validated by studying their ability to interpret design corpuses. We can quote among those approaches:

3.1. The Functional Behaviour State Model (FBS)

The FBS model, described for example in [8], consists in modelling the design process as a transformation from required functions (F) to designed structure (S), passing through the behaviour (B) (Figure 7). A distinction is made between the expected behaviour (Be), which is a proposed behaviour built by designers to fulfil the needs described by the functions, and the behaviour derived from the structure (Bs), which describes the actual behaviour of the structure proposed.

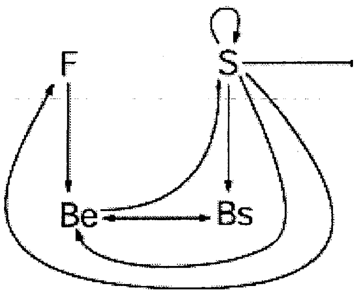

Figure 7. The FBS model [8]

3.2. The properties driven product development model (PDD)

In this model, the design process is considered as a transformation process that aims at translating the expected product properties into characteristics describing the product. Weber introduces this model [9], and compares the distinction between properties and characteristics to the distinction between internal and external properties [10], or between functional requirements and design parameters [11].

3.3. Darses's approach

Contrary to all the sequential design models, Darses lays down that designers deal simultaneously with functional, structural and physical aspects of the product they are designing [12]. Indeed, designers mind seems to need to rely on a physical representation even to deal with functional aspects.

3.4. The main interest for our topic

All those descriptive approaches propose different categorisations of domains that the design process passes through, and describe different elementary processes linking those domains. As the purpose of our research deals with the evaluation of the design process, our field of interest can be limited to the elementary process that deal with either evaluating or analysing a proposal according to the needs definition, or building or modifying the needs definition. In this sense the model described in the section 4 includes some aspects of the approaches described above.

4. The proposed model of the evaluation process

Taking into consideration the retained aspects of reviewed works above, a model of the evaluation process is under development. Its purpose is to provide a cartography of the evaluation space covered by the designers throughout the design process. According to the definition of the design process retained, the needs on one side and the product on the other side set up its borders. Between those two limits several interpretation of the evaluation process are possible, to support the zigzagging followed by designers. Those interpretations are depicted in Figure 8.

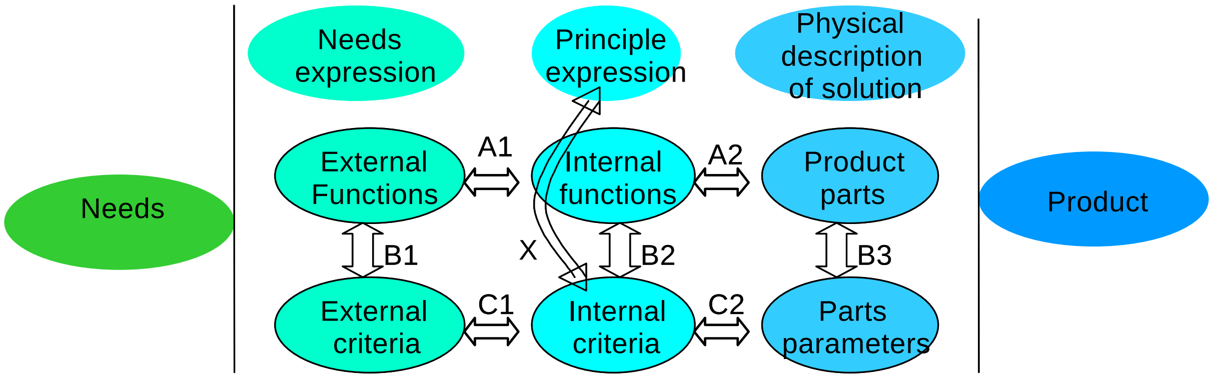

Figure 8. The model of the design process

4.1. Link to reviewed approaches

The expression of the needs is depicted in this model in two different ways. Indeed, according to functional analysis (FA), the needs are expressible by a set of expected functions to be fulfilled, the external functions. The performance level specified for these functions is expressed according to a set of external criteria, following thus the formalism of FA (B1). The physical description of the product is expressible using both products parts, that define the shape of the product, and parameters, or physical specifications that apply to those parts (B3).

Between these two domains, transition can be depicted by either three ways: first, the link between external functions and products parts (A1 and A2) passes through internal (or technical) functions. The building of this link can be supported using the functional analysis tools presented in section 2.1. FA tools can also assist designers in associating internal criteria to internal functions (B2). Second, once external criteria, internal criteria and products parts parameters have been identified, HoQ can support the identification and the characterisation of the links between them (C1 and C2). Finally, in regard with the issues highlighted in section 3, the transition between needs and products can occur via a description of a principle describing the product. So-called principle is ill defined, except by the fact that is describes neither a physical description of the product nor the needs, and that it is not formalised in functional terms. Approaches reviewed above partly address this issue, proposing the terms behaviour, structure or concept. We can note that intermediate criteria used in QFD can address this feature (X). They are classified as internal criteria, regarding the fact that they depends of the proposal made. An example of the typical features we include in these different domains is given in the part 5.1 of this paper.

4.2. Discussion

Providing a cartography of the design process allows characterising the ways designer follow to perform evaluations of proposals. By this characterisation, it should be possible to specify a set of requirements for a tool that aim at supporting the evaluation process, taking into account the natural rationale of designers. Performing this task in a rigorous way requires to validate previously this model; this issue is addressed in section 5. The perspectives of this research work are thus obviously to first specify a tool, and then to develop it.

Some shortcomings are here and now present within this model that is incomplete. The main of them concerns the need definition. Indeed, functional analysis, and our work tends to validate its relevance, recommends to define the needs using functions and associated features (criteria, level and flexibility), and also constraints. Constraints are an expression of some limitations within which designers can conceive a product to fulfil the functional criteria. Those constraints can have repercussions on the possible level given to criteria, external as well as internal. The model proposed must be able to take account of those constraints and their repercussions. Another critical issue concerns the balance addressed to functions and criteria. Indeed this balance is an important feature that supports the expression of strategies. Finally, following the assumption that the value concept is relevant to measure the comprehensive performance of a product, the model must be able to manage the duality of value, as it supports simultaneously the needs and the resources consumption aspects. Those two issues are addressed partly in [4]

5. Use on a protocol study

5.1. Procedure

To validate the proposed model, its ability to fit with a real design situation was tested. For this purpose the corpus DPW. 94.1.14.5 from the “Delft Design Protocol” [13] was studied. It involves three professional design engineers. From the corpus the elementary steps that deals with either need definition or evaluation were extracted. The criteria used during those elementary steps were classified within three different categories, derived from those identified in part 4. These are distinguishing, from an overall point of view, between criteria that address either the expression of the need, or the physical definition of the solution, or the so-called “principle”. Table 3 gives an example of the achievement of this procedure.

Table 3. Examples of the protocol study procedure.

Time	Dialogue extracted	Recorded criterion	Recorded category
00:18	And it’s an off road bike so you’d need a real rugged attachment or a rigid attachment	Rugged or rigid attachment	Needs expression
00:19	So you have to do it much tighter…	Strong tightening	Principle expression
01:06	That’s probably got enough to hold the support the weight	Material quantity	Physical description of solution

5.2. Results

Following the procedure described above, the 68 first minutes of the protocol were recorded

and analysed. Figure 9 gives a representation of the progress of the design process, along the temporal axis. We can note that the designers continuously zigzag among the three criteria categories depicted in section 4. According to this result, the Darses's assertion that designers deal iteratively (contrary to sequentially) with functional, structural and physical criteria is validated following a different expression. Indeed the three categories chosen for this study were not exactly Darses's. Nevertheless the problematic addressed is globally the same, according to the authors, since it deals with both the non-linearity of design rationale and its extension along (at least) three different domains.
This protocol study concludes to requirements for a tool assisting designers to deal with criteria from the different categories proposed in the model simultaneously and dynamically.

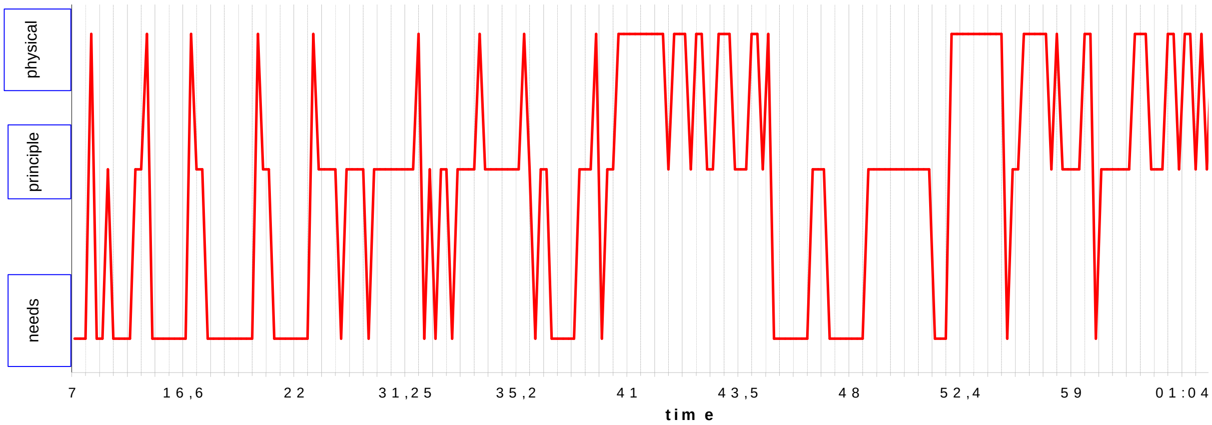

Figure 9. The procedure result.

6. Conclusion

Engineering design consists in translating needs into a product definition. Some methods, which aim at supporting this translation process have been reviewed. They were experienced on an industrial case study that allows us to identify some shortcomings. In regard with a review of some descriptive studies of the design process, we identify the sequential paradigm on which these methods were built as the source of the shortcomings raised. A protocol study then allows us to highlight the gap between this sequential approach of the design process (i.e. the needs achievement follows strictly its expression) and a real design process. From here we have proposed a model that aim at formalising the expression of the features raised during the evaluation occurring during the design process, at formalising the expression of the links between them, and at supporting the dynamics of such a process. This model is based on a multi-domain view of the space covered by designers, according to conclusions drawn from the study of a real design situation.

In addition with an interest in understanding the design rationale followed during a real design process, this model should lay down the bases on which we plan to develop a tool with objective to support the design activity. Without being prescriptive, this tool should help designers to formalise their evaluation, by assisting the interactive construction of the evaluation criteria that apply simultaneously to the needs and both the designed product principle and its physical description. The most important supply of this tool should be its use as an interaction framework, that would enable each product life-cycle stakeholder to communicate inside the whole integrated design team about their own constraints on a more effective, accurate and relevant way.

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