3TU. School for Technological Design

STAN ACKERMANS INSTITUTE

New criteria for assessing a technological design

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1. Introduction

In 2010 we developed a set of criteria for the evaluation of technological design projects of the PDEng programmes of the Stan Ackermans Institute (SAI). We have separated the evaluation of the final *outcome*, the technological design (see [1]), from the evaluation of the *process* that has led to the outcome(see [2]). The main reason for this separation is that the project is teamwork and that the supervisors may have a substantial influence on the outcome because they are responsible for an acceptable final result. So in theory it may be that the outcome of the design project is very good but that the contribution of the trainee is poor and it also may happen that the outcome is not very exciting, but the contribution of the trainee was splendid. The criteria, documented in [1], are based on 9 aspects of a design and measured by 27 indicators, which all have an *operational* scale, which means there is an objective method to determine indicator values. This is important if one wants to compare the quality of different technological designs.
In the past academic year we have experimented with the criteria in all programmes of SAI. After that we have evaluated the applicability of the criteria.

The following observations were made:

1. The evaluation takes too much time, because:
   - there are too many indicators.
   - some indicators are too difficult to apply (e.g. 'complexity' and "economical value').
2. Some indicators are not applicable in every situation and so the evaluators have to decide which indicators are relevant and which are not. This is confusing.
3. Some indicators should be relative with respect to the (given) problem.
4. There was no recipe to come to a final judgment.

In some programmes a short course was given to trainees before they started their project. This turned out to be very useful because the trainees started with thinking about the value of their contributions. It was a pity that the evaluators did not take the course, which might have helped them to overcome some of the appearing difficulties.

Based on these experiences we have redesigned the evaluation of technological designs. We have made the following changes:
1. We distinguish five *aspects* (instead of the 9 before) that cover only 12 *criteria* (instead of the earlier 27 indicators).
2. Each criterion is valued by a 5-point ordinal subject scale. We offer one interpretation of the scales, but the evaluators have the freedom to take another one depending on the type of project.
3. The criteria (called indicators before, see the report 'criteria for assessing a technological design) are only offered as an aid to compute the aspects' value in case the members of the evaluation team cannot agree.
4. We offer a simple recipe to determine a final mark.

2. Technological designs

In [1] we give an extensive analysis of the merit and the objectives of the SAI programmes. Some of it we summarize here and we put the programmes in the international context.
The programmes of SAI are programmes that fit in the third cycle of the Bologna declaration ([3]). This means that the trainees are expected to deliver a scientific or technological contribution to society In case of engineering programmes it is important to determine what a 'contribution' should be. In order to do so, we cite the following definition of 'engineering" of the American Engineering Council of Professional Development (ECPD/ABET) (see [4]):

*"The creative application of scientific principles to **design** or **develop** structures, machines, apparatus, manufacturing processes or works…".*

Meaning the solution of an engineering problem is an *artifact*, i.e. a man-made system that is either a tangible or an intangible product, or a process. Artifacts as we see them, serve an economical or societal purpose, which means they have a *value*. Artifacts we consider are designed according to *scientific principles*, which means that there should be a systematic method for *synthesizing* the design and that a design is evaluated using scientifically based *analysis* methods. In our programmes we consider the technological design of an artifact as the outcome of the project.
A technological design of an artifact can occur in various modalities. One is an abstract representation of the artifact in the form of a symbolic model, which can be an informal model, a mathematical model or a computer model. Another modality is a physical model in the form of a prototype. In most cases a technological design consists of more than one model, each describing a facet of the artifact.
A technological design serves the following purposes:

- Communication between the stakeholders about the artifact;
- Documentation of the artifact for instance for instructing users, installation, maintenance and future modifications;
- Analysis of the artifact. The analysis relates to the behavior of the artifact in a certain context. We distinguish formal analysis and experimental analysis;
- Construction of the artifact, which means that it serves as blue print.

We distinguish three kinds of projects: (1) a technological design of a complete artifact, (2) a design of a component of a larger artifact, (3) a redesign or a reconfiguration of an existing artifact.
In each project the emphasis can be on different phases of a design. So the focus can be on the requirements, on the modeling or on the analysis of the artifact.

3. Evaluation of technological designs

To evaluate technological designs we distinguish 5 aspects or views:

1. **Functionality**. Answering the question "What is the artifact doing in its environment?"
2. **Construction**. Answering the question "How will the artifact do this?"
3. **Realizablity**. Answering the question "How can the artifact be realized?"
4. **Impact**. Answering the question "What are the risks and benefits of the artifact for its environment?"

5. **Presentation**. Answering the question “What does the artifact look like in all its details?”

In total we distinguish 12 *criteria* to evaluate an artifact. They are grouped per aspect. We give for each criterion a 5-point scale varying from 1 to 5. The idea is that the members of an evaluation team express their judgment as a value on this scale. When the range of values for one criterion is at least two among the team members, we recommend a detailed analysis of the different judgments rather than merely averaging the individual members’ scores. For this analysis we offer a set of quantitative indicators to make an objective judgment.

Some criteria can be interpreted in different ways. For each criterion we suggest one, but the evaluation team can choose its own in a concrete situation. There are two ways to define scales. One interpretation is the *justification* or the *quality* of the argumentation, while another interpretation is the *value* of the solution. For example one could have found a very profitable solution but have no arguments that it is the best there is. On the other hand one could have found a straightforward solution but a proof is given that there is no better solution available. It is up to the evaluation team to choose an interpretation; however the choice should be documented. (This has to be incorporated in the examination rules.)

4. The criteria

The criteria are grouped per aspect. They all have a 5-point scale.

1. Functionality

a. *Satisfaction.*

This concerns the extent to which the designed artifact satisfies the requirements. Often the formal requirements develop during the project, based on mere informal initial requirements. In case the requirements are relatively easy to meet, the evaluation team will be more strict in weighing the discrepancies than in case the requirements are very difficult. So in a way the judgment of the evaluation team will evaluate the satisfaction relatively to the difficulty of the problem.

1	2	3	4	5
Poor fit to the requirements	Insufficient fit to the requirements	More or less meets requirements	Meets requirements	Exceeds requirements

b. *Ease of use.*

This concerns the ease of use for the stakeholders. The stakeholders are e.g.: end users, operators, engineers is responsible for installation and maintenance of the artifact.

1	2	3	4	5
Very difficult	Difficult	Acceptable	Easy	Very easy

c. *Reusability.*

The extent to which the artifact can be used in other situations.

1	2	3	4	5
No reuse	In same context, same scale	In same context, different scale	In different context, same domain	In different domains

We distinguish the notions of ‘scale’, ‘context’ and ‘(application) domain’. In different disciplines these notions may have different meanings.

2. Construction

a. *Structuring.*

This concerns the partitioning of the artifact in logical or physical *components*. Structuring may use *hierarchy*, which means that subsystems can be considered as components themselves. The ‘structuring’ is often called the ‘architecture’ of an artifact. Structuring is important to understand the construction of an artifact and it is used for instance for manufacturing and maintenance. The structuring has 4 elements: (1) overview, with or without hierarchy, (2) low degree of coupling between components, (3) high cohesion within components, (4) clear interfaces.

1	2	3	4	5
None	1 out of 4	2 out of 4	3 out of 4	All 4

b. *Inventivity.*

The measure for originality. One way to express this is by the surprise factor.

1	2	3	4	5
No surprise at all	Surprise for laymen	Surprise for peers	Surprise for professionals	Surprise for supervisors

c. *Convincingness.*

This concerns the evidence that the construction will work and has the defined functionality. Here we distinguish several forms of proof. An empirical proof is a statistical argument based of either simulations or on experimentation with a prototype.

1	2	3	4	5
No proof	Informal proof	Empirical proof based on simulation	Empirical proof based on a prototype	Formal and empirical proof

3. Realizability

a. *Technical realizability*

This concerns certainty that it is technically possible to produce the artifact.

1	2	3	4	5
Unkown if it can be produced	Informal arguments	Model-based analysis	Prototype is realized	0-series is produced

b. *Economical realizability*

This concerns the *business case* for the artifact. A business case can be scored in two ways: the analysis is convincing or the outcome such that it is easy to convince stakeholder to invest in it. The next scale combines the two.

1	2	3	4	5
No business case	Accurate estimate of costs	Accurate estimates of costs and revenues	A well-substantiated financing plan	Business case committed by stakeholders

4. Impact

a. *Societal impact.*

This concerns the influence the artifact will have on societal values such as sustainability or health and well-being.

1	2	3	4	5
Negative impact	No impact	Low positive impact	Moderate positive impact	High positive impact

b. *Risks*

This either may concern the risks of the artifact during development of the artifact or the risks related to the use of the artifact. The analyses of the risks as well as the measures for mitigation are important.

1	2	3	4	5
Risks not analyzed	Risks informally analyzed	Risks scientifically analyzed	Risk mitigation measures taken	Risks scientifically analyzed and adequately mitigated

5. Presentation

The presentation includes the documentation of the artifact, but it may also concern a prototype or an animation.

a. *Completeness*

1	2	3	4	5
Very poor	Poor	Marginal	Good	Very good

b. *Correctness*

1	2	3	4	5
Unreliable presentation	Many errors found	Acceptable number of errors	Few errors found	No errors found

5. Final mark

Six of the 12 criteria concern the kernel of the artifact: the functionality and the construction, while the six others cover other aspects. To reach a final judgment, the scores on the 12 criteria need to be aggregated. This can be done by means of multiplicative weights, which allows to express differences in relative importance among the criteria. By default, all weights could be taken equal; alternatively, the weights for the criteria 1a … 2c could be made bigger than those for 3a … 5b. Also other motivated choices can be appropriate. In case multiplicative weights are used the motivation to do this should be documented.

6. References

1. Kees van Hee and Kees van Overveld. Criteria for assessing a technological design. SAI report 2010.
2. Criteria for assessing the design process of a technological design. SAI report 2010.
3. Bologna declaration. http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/122EN.pdf
4. Engineering Council of Professional Development. Canons of ethics for engineers. New York (1947)

Appendix - Evaluation Form Aspects Design*

Project name	
Designer	
Company	
Company supervisor	
University supervisor	

Scale:

fail	poor	fair	good	excellent
1	2	3	4	5

Aspects for assessing design	**Criteria**	**Value per criterium**	**Weight criterium**	**Score aspect**
Functionality	Satisfaction			
	Ease of use			
	Reusability			
Construction	Structuring			
	Inventivity			
	Convincingness			
Realizability	Technical realizability			
	Economical realizability			
Impact	Social impact			
	Risks			
Presentation	Completeness			
	Correctness			
			Total score	

* *Please, use the scale description on the following page when filling out the evaluation form.*

Aspects for assessing a technological design

1. Functionality

Criteria	1	2	3	4	5
	Fail	**Poor**	**Fair**	**Good**	**Excellent**
Satisfaction	Poor fit to the requirements	Insufficient fit to the requirements	More or less meets requirements	Meets requirements	Exceeds requirements
Ease of use	Very difficult	Difficult	Acceptable	Easy	Very easy
Reusability	No reuse	In same context, same scale	In same context, different scale	In different context, same domain	In different domains

2. Construction

Criteria	1	2	3	4	5
	Fail	**Poor**	**Fair**	**Good**	**Excellent**
Structuring	None	1 out of 4	2 out of 4	3 out of 4	All 4
Inventivity	No surprise at all	Surprise for laymen	Surprise for peers	Surprise for professionals	Surprise for supervisors
Convincingness	No proof	Informal proof	Empirical proof based on simulation	Empirical proof based on a prototype	Formal and empirical proof

3. Realizability

Criteria	1	2	3	4	5
	Fail	**Poor**	**Fair**	**Good**	**Excellent**
Technical realizability	Unkown if it can be produced	Informal arguments	Model-based analysis	Prototype is realized	0-series is produced
Economical realizability	No business case	Accurate estimate of costs	Accurate estimates of costs and revenues	A well-substantiated financing plan	Business case committed by stakeholders

4. Impact

Criteria	1	2	3	4	5
	Fail	**Poor**	**Fair**	**Good**	**Excellent**
Social impact	Negative impact	No impact	Low positive impact	Moderate positive impact	High positive impact
Risks	Risks not analyzed	Risks informally analyzed	Risks scientifically analyzed	Risk mitigation measures taken	Risks scientifically analyzed and adequately mitigated

5. Presentation

Criteria	1	2	3	4	5
	Fail	**Poor**	**Fair**	**Good**	**Excellent**
Completeness	Very poor	Poor	Marginal	Good	Very good
Correctness	Unreliable presentation	Many errors found	Acceptable number of errors	Few errors found	No errors found

3TU.School for Technological Design, Stan Ackermans Institute offers two-year postgraduate technological designer programmes. This institute is a joint initiative of the three technological universities of the Netherlands: Delft University of Technology, Eindhoven University of Technology and University of Twente. For more information please visit: www.3tu.nl/sai.