

## A CONCEPT DEVELOPMENT SPACE FOR CONCEPTUAL DESIGN METHODOLOGY

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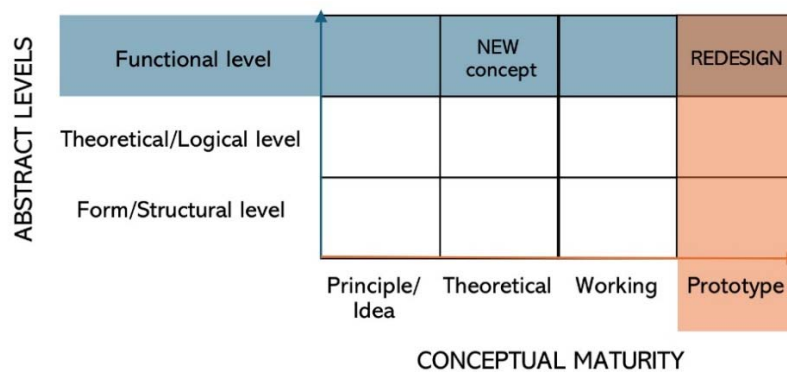
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**Abstract:** In today's accelerated industrial and engineering processes, timely, fast, and best-fit decisions are essential to produce successful technical solutions and products. In this context, conceptual design can be understood as a series of decisions that affect the state of the entire life cycle of the designed system. One of the main goals of this paper is to support this series of decisions and to create a description of the concept development space model.

**Keywords:** *concept state, concept development space, uncertainty space, target region, iterative conceptual design*

### 1. INTRODUCTION



**Figure 1.** *The concept-state matrix*

The conceptual stage can be found not only in the design of new products, but also in the redesign and development of each existing product. Therefore, the division of the design process into time stages must be distinguished from the abstraction level of the product, where the conceptual state is not a time stage, but a level of abstraction. So, it is possible to examine the redesigned product in a mature life cycle stage.

## 2. DECISION SUPPORT AND CONCEPTUAL DESIGN

### 2.1. The strategic decision space

By further developing the conceptual design model formation system (Schumacher, Daoud, Petersson, & Wagner, 2012), we can obtain the location of decisions in the space of design abstraction and concept maturity. This space shows when, at what level, and with what impact a decision is made in the design process. Figure 1 shows where the decision is in the matrix of design abstraction and concept maturity. The  $D_1$  axis of Figure 2 represents the design abstraction level, which shows the depth of the concept design, i.e. whether it is at the functional, conceptual, form/structural design level. The  $D_2$  axis characterizes the concept maturity level, the degree of realization, showing whether it is a conceptual solution/basic concept, theoretical model/study model/mock-up, working model/functional model, prototype/pre-series model. This is the representation of concept maturity, which shows how mature the concept is. Figure 1 also highlights that the dimensions of design abstraction and concept maturity are partially independent.

For example, when a material selection decision is changed due to new conditions, the operating principle and structural structure of the system are also affected by the change, which can thus be considered a conceptual-level design step. Such a case exists if the previously selected material quality seal is not available and therefore the construction geometry needs to be changed to achieve the appropriate tightness. Figure 1 also illustrates that the conceptual decision can be made in the prototype stage, yet its level is a conceptual abstraction-level decision.

The level of design abstraction also shows the complexity of the design requirements during design. From this, redesign can also be defined as a change in the requirements structure.

The conceptual design process can be defined as the designer developing and evaluating concept states that meet the requirements. Furthermore, due to changes in the design constraints, a redesign process may begin, resulting in the development of new product variants, i.e. concept states.

## 2.2. The Concept Development Space

Analysing the development of the concept, it can be defined in a three-dimensional system as the Concept Development Space (CDS). The first dimension can be taken based on the function-principle-form logic (Koller, 1994). This is the dimension of conceptual depth, the abstraction level ( $D_1$ ), where the designer makes decisions. This corresponds to the conceptual design according to VDI. The second dimension is the system of concept maturity states of Takács (Takács & Aghakhani, 2023). This is the concept maturity dimension ( $D_2$ ). The third dimension ( $R$ ) was defined based on object catalogue approach by Roth (Day, Gasparri, & Aitchison, 2019), (Roth, 2002). It describes the physical implementation or concretization and is made up of four parts: the material state ( $A$ ), geometric design ( $G$ ), state of interface connections ( $K$ ) and the technological state ( $T$ ).

## 2.3. The concept state

The state of the concept can be defined as a point in the concept development space, where the concept state of the  $i$ -th alternative at the  $k$ -th iteration step is:

$$K_i^{(k)} = (D_1^{(k)}, D_2^{(k)} R_i^{(k)}) \in K. \quad (1)$$

These are constantly evolving towards the desired target region, and are therefore time-dependent, i.e. dynamic concept states:

$$K_i^{(k)} \quad (2)$$

where the concept state of the  $i$ -th alternative in the  $k$ -th iteration step. The desired concept state evolves towards  $K_i$  and the desired target region, i.e.:

$$K_i^{(k)} \rightarrow T(t) \quad (3)$$

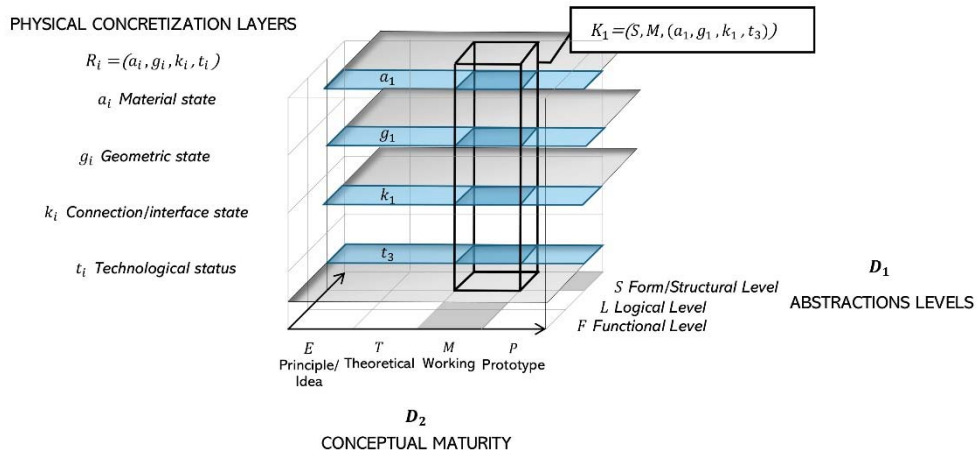
So, the process is dynamic, iterative and goal oriented. Furthermore, the concept state is not a point value, but a state that evolves over time. During the development process, the width of the intervals decreases, which usually shows a decrease in uncertainty and an increase in the maturity of the concept. However, in the case of redesign processes, it can also temporarily increase. Therefore, the concept development process can be modelled as a goal-oriented, interval-based state transition system that manages uncertainties.

## 2.4. Configuration status

The configuration state corresponding to the physical concretization states:

$$R_i = (a_i, g_i, k_i, t_i), \quad (4)$$

where  $a_i$  is the material state,  $g_i$  is the geometric state,  $k_i$  is the connection/interface state,  $t_i$  is the technological state. Figure 2 illustrates the physical concretization layers in the CDS.



**Figure 2.** The spatial location in case of  $K_1$

## 2.5. Configuration state transition

A configuration state transition occurs when one or more of the physical concretization layers changes

$$R_i \rightarrow R_j. \quad (5)$$

Let

$$R_i = (a_i, g_i, k_i, t_i), \quad (6)$$

and

$$R_j = (a_j, g_j, k_j, t_j) \quad (7)$$

where  $R_i$  and  $R_j$  represent two consecutive configuration states. The initial state is illustrated in Figure 2, and the transitions are illustrated in Figures 3.

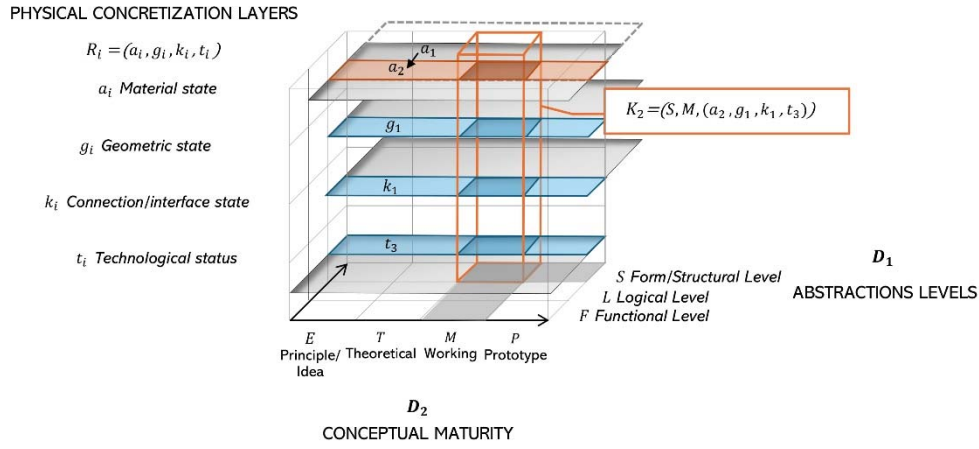


Figure 3. The spatial location in case of  $K_2$

Table 1  
Concept states and reasons for changes

Concept status	Reason for change	State transition
$K_1 = (S, M, (a_1, g_1, k_1, t_3))$	Initial state	-
$K_2 = (S, M, (a_2, g_1, k_1, t_3))$	Material change	$a_1 \rightarrow a_2$

### 2.6. Concept status matrix

Conceptual abstraction levels and concept maturity states can be described as a two-dimensional concept state matrix, where the dimension of the abstraction levels representing conceptual depth is:

$$M = D_1 \times D_2 , \tag{8}$$

where  $D_1$  is the conceptual depth,  $D_2$  is the concept maturity. The cells of the matrix define a concept state. Expanding this matrix into a spatial model, the model considers not only the depth of thought and the state of completion of the concept, but also the level of physical concretization, the third dimension by adding layers of concretization. With this expansion, the concept development space becomes definable.

$$\mathcal{K} = D_1 \times D_2 \times R, \quad (8)$$

where  $R$  is the physical concretization states and  $\mathcal{K}$  is the concept development space.

The novelty of the presented model is that it defines the three dimensions:

- the conceptual depth,
- the concept maturity and
- the set of physical concretization configurations

as an integrated multidimensional decision space, the Concept Development Space. Thus, the model not only describes the planning process, but also provides a decision-support representation. Thus, the state of the concept becomes a clearly defined place in the concept development space. In Figure 2, the black block represents a clearly defined conceptual state ( $K_i^{(0)}$ ). For example, a redesign, such as a necessary material change, can be represented by the material state of the given solution configuration being transferred from state  $a_1$  in the concretization layer to state  $a_2$  in the concept development space. In this way, a transition model between the concept states can be defined between the configurations.

## 2.7. Uncertainty space

Every concept state has uncertainty, since information is incomplete at this design stage. Since the parameters of every alternative in the conceptual design stage can be generated with uncertainty, these uncertainties are found everywhere in the concept development space and therefore can be assigned to every concept state. Let:

$$B(K_i^{(k)}), \quad (9)$$

the uncertainty range for the  $k$ -th iteration concept state of the  $i$ -th alternative. The uncertainty space:

$$\mathcal{B} = B_{D1} \times B_{D2} \times B_R, \quad (10)$$

where  $B_{D1}$  is the structural uncertainty related to the abstraction level,  $B_{D2}$  is the maturity or information uncertainty, and  $B_R$  is the uncertainty of the totality of the physical concretization. As the concept gradually becomes more precise, more defined and more mature, the uncertainty range generally decreases. However, in the design process, there are also possible steps back between concept states, for example in the event of new requirements, changes in functionality, or changes in boundary conditions. As a result, uncertainty can also increase during development.

## 2.8. Target region

Let  $\mathcal{K}$  be the concept development space. The target region is the time-dependent subset of acceptable concept states in the concept development space at a given iteration (T):

$$T^{(k)} \subseteq \mathcal{K}, \quad (11)$$

which is the set of acceptable concept states that satisfy, at a given iteration the decision maker's preferences, the functional requirements, and the physical feasibility conditions.

The goal of concept development is to reach a concept state where:

$$K_i^{(k)} \in T^{(k)} \quad (12)$$

i.e. the design alternatives continuously approach the target region containing the desired concept states.

## 3. SUMMARY

Following the theoretical studies explained in the previous subsections, conceptual design can be defined as an iterative decision process that is not static but takes place in an uncertain and partially defined space. The driving force of the process, the target region, defines the direction of the development process, towards which the alternatives develop.

The steps of the continuous interval-based concept development process described so far are:

1. Definition of concept states  $K_i^{(k)}$ ,
2. Target value-based evaluation,
3. Interval-based multi-criteria ranking,
4. Selection of the next concept state,
5. Feedback and new iteration.

The process can be repeated until the target region is reached or until a sufficient level of information for the design decision is reached.

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**REFERENCES**

- Day, G., Gasparri, E., & Aitchison, M. (2019). Knowledge-based design in industrialised house building: A case-study for. *Lecture Notes in Civil Engineering*, 989-1016. doi:[http://dx.doi.org/10.1007/978-3-030-03676-8\\_40](http://dx.doi.org/10.1007/978-3-030-03676-8_40)
- Koller, R. (1994). *Konstruktionslehre für den Maschinenbau* (3 ed.). Berlin, Germany: Springer. doi:<http://dx.doi.org/10.1007/978-3-662-08165-5>
- Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.-H. (2007). *Engineering Design*. London: Springer London. doi:<http://dx.doi.org/10.1007/978-1-84628-319-2>
- Roth, K. (2002). Design catalogues and their usage. *Engineering Design Synthesis*, 121-129. doi:[http://dx.doi.org/10.1007/978-1-4471-3717-7\\_8](http://dx.doi.org/10.1007/978-1-4471-3717-7_8)
- Schumacher, G., Daoud, F., Petersson, Ö., & Wagner, M. (2012). Multidisciplinary Airframe Design Optimisation. (I. Grant, Ed.) *28th International Congress of the Aeronautical Sciences*, 1-13.
- Takács, Á., & Aghakhani, A. (2023). The meaning of concept in design methodology. *Design of Machines and Structures*, 13(1), 5-10. doi:<https://doi.org/10.32972/dms.2023.001>