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Investigation of the Systemic View in Designing

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Abstract
A system interacts with its environment to satisfy its requirements. Designing involves developing systems. Therefore, designing should involve developing the concept of both the system and its surrounding during the design process. Depending on how the concept of the system changes will impinge on the concept of the environment, and vice-versa; design must co-evolve the concepts of both the system and its environment. Based on this argument, a systemic view has been proposed in this paper that consists of: System, Subsystem, Elements and Environment as its constructs, where each of these constructs are *explicit* and *evolvable* during design. A comprehensive review of literature on design models to analyse the use of the systemic view in designing revealed that while the concept of systems is used, implicitly or explicitly, by many design models, the concept of environment is rarely used as an *explicit evolvable* construct in designing. An example of system-environment co-evolution during design from one among several protocol studies conducted by the authors is presented to show the importance of environment as an *explicit evolvable* construct in design. The systemic view developed is empirically validated using the above protocol studies. The validation involved checking whether or not all the constructs in the proposed systemic view are naturally present, albeit implicitly, in these design sessions.

Nomenclature

System	S
SubSystem	SS
Environment	Env
Element	El
Designer1	D1
Designer2	D2
Designer3	D3
Problem Brief1	P1
Problem Brief2	P2

1. Introduction

Designing involves developing a system that interacts with its environment in order to satisfy the requirements for the system. Therefore, developing the idea of *both* the system and its environment are important in designing. Few researchers, e.g. Asimow [1], Deng et al. [9], Hall [12], Hubka and Eder [15] considered the interactions between system and environment as an important aspect of designing.

While the primary focus of designing is to develop a system, environment must also be identified, specified, and variously modified, in order to ensure that they together are capable of fulfilling the requirements. Due to the primary focus of designing on the system, current literature on models of designing either completely ignores this systemic view – the perspective of taking both system and environment as explicit constructs in these models – or focus only on the system as the evolving construct during design.

The objectives of this paper are to:-

1. Establish the importance of "Environment" as an evolvable construct in designing. Identify how well current literature proposes the use of the systemic view in designing and systems engineering, as an explicit evolvable construct.
2. Propose a systemic view as inherently present in real designing that should be present in models of designing as an explicit, evolvable construct.
3. Validate the presence of the constructs of the systemic view in designing, using analyses of natural design processes.
4. Demonstrate the existence of System-Environment Co-evolution in natural design processes.

2. Literature survey

2.1 Importance of Environment in Designing

Asimow [1] states that 'environment of society' greatly affects a design project, and environment is reciprocally affected, in large or small measure, by the consequences of the design project. Asimow explains in detail the various interactions between engineering systems and their environment [1], such as socio-ecological influences on engineering design. According to [12], the system designed is developed from environment. [15], in their 'Theory of Technical Systems', defined environment and discussed specifically about 'active environment', the portion of the environment that directly interacts with the system and plays an important role in the performance of the system. [9] considers environment as an explicit element in their Function-Behavior-Working Environment-Structure model of designing. They showed that information of 'working environment' is useful to the exploration of functional design solutions.

2.2 Systemic view and its constructs in literature

[1] used a systemic view which consists of the following constructs: system, subsystem, components and parts. Although Asimow considered the interactions between system and environment as important, 'environment' was not used in his model of designing as an evolvable construct. [12] in his systems engineering process used a systemic view which consists of system, environment, subsystems and objects. Hall also considered environment a major factor in the design process, and considered 'initial environment' and 'final environment' in his model of the systems engineering process at the beginning and at the end, but did not use 'environment' as an evolvable construct during the process [12]. Hubka and Eder in their Theory of Technical Systems [15] used a systemic view that consists of: system, subsystem, elements and components. They also defined 'environment' and 'active environment', which were used in the model of designing. INCOSE [17] for the systems engineering process used a systemic view with the following constructs: system, element or segment, subsystem, assembly, subassembly, components and parts.

2.3 System-Environment Co-evolution in Designing

The need for a system arises from the environment. As system is developed the environment also gets modified. Hence, the changes in the system lead to change in the environment. There are various examples in literature on the evolution of products where changes in the system have led to changes in the environment, and vice-versa. An example for this is development of writing devices from the likes of pen and inkpot – where design effort variously focused on either the pen as the system, with the inkpot being given and therefore part of the environment, or the inkpot as the system to be designed, with the pen being part of the 'given' environment. Subsequently, the two were considered together, leading to design of integrated pen and inkpot systems, such as a fountain pen or a ballpoint pen [27].

We argue, therefore, that a systemic view must consist of explicit constructs to represent both the system and its environment, and must be incorporated into models of designing as constructs that are potentially evolvable during design.

2.4 The proposed systemic view

We propose the following systemic view, which consists of the following constructs: system, sub-system, elements, relationships and environment. Here both system and environment are evolvable constructs in the process of designing. These constructs are defined as follows. A **system** is an overall entity at any level of abstraction. A **sub-system** is a subset of a system. An **element** is a basic entity of a system or a sub-system which cannot be further sub-divided. An **environment** refers to all subsets of the universe apart from the system within which the system must work. The relationships between these constructs can be explained as follows. A set of elements together forms a sub-system. A set of elements and sub-systems together forms a system. System is also characterized by an imaginary system-boundary that separates it from the environment. System needs a particular environment (which is outside the system-boundary) to satisfy its requirements. For a subsystem or element, anything outside its boundary is considered to be environment including the other elements and subsystems within the system.

These constructs are illustrated with a *ballpoint pen*, which is a system made up of *refill* (SS), *body* or *cover* (SS) and a *cap* (El). The *refill* is a sub-system consisting of elements like *nib*, *ink* and *ink reservoir*. The *body* or *cover* is another sub-system consisting of elements like *upper cover* and *lower cover*. The environment for the *ballpoint pen* consists of *papers on which it has to write* and *an agent which uses it to write*.

2.5 Importance of a Systemic View in designing

Various models of designing (See Table 1) are reviewed here to investigate whether and how these take into account a systemic view.

Asimow [1] models the overall pattern of a design-project, which starts from primitive need and continues through the following phases: feasibility study, preliminary design, detailed design, planning for production, planning for distribution, and planning for consumption, of which the first three phases belong to the primary design process. The systemic view considered here is made of system, subsystems, components and parts.

Hall [13] used the systemic view which consisted of system, subsystem, objects and environment was proposed to support investigation of systems engineering. He used morphological analysis (means to decompose a general problem or system into its basic variable becoming a dimension on a morphological box) to investigate systems engineering, which revealed the three fundamental dimensions: time dimension, logic dimension and knowledge dimension. With the first two dimensions a morphology of systems engineering process called activity matrix is produced. The logic dimension is a model of the problem solving procedure.

Ullman *et al.* [8] proposed "Task/Episode Accumulation [TEA] model" of designing to explain the mechanical design process. The tasks involve *conceptual design*, *layout design*, *detail design*, and *catalog selection*. The episodes include *assimilate*, *plan*, *specify*, *repair*, *verify*, and *document*. In [8], the authors consider the '*design environment*', which is the environment in which design takes place.

Gero [11] proposes a descriptive design model, where the purpose of designing is to transform a set of functions F into a design description D in such a way that the artifact is capable of producing these functions. This can be represented as a transformation process F→D. A structure is developed, and transformed into a design description i.e. S→D. This structure gives a *derived behavior* (S→Bs). The function is transformed to *expected behavior* (F→Be). The expected and derived behaviors are compared (Be <--> Bs) and if Be and Bs match each other, a final design description (D) of the artifact is produced. Systemic view is made explicit in Gero [1990] only when defining the function of the product.

Visser [26] proposed a descriptive model of designing. At a high level of abstraction, the design process may be described as proceeding in iterative cycles, and leading progressively from a global problem specification to a detailed solution. Both these proceed through successive levels, reducing abstraction until the implementation level is reached. On one hand, problems are worked out in breadth and decomposed into sub-problems, which imposes integration of intermediate solutions. On the other hand, problems are worked out in depth: each solution to a problem is taken as a problem to be solved until a final solution is reached. This solution has to be detailed and concrete enough to specify its manufacturing details (that is, in the case of artifacts' design). In this model, a problem is decomposed into sub-problems, solutions are found for each and integrated. This suggests implicit presence of the systemic view in the design process.

Blessing [2] developed PROSUS (Process-based Support System) – a prescriptive approach for designing. A *design matrix* is at the core of PROSUS; this is a structured set of *issues* and *activities*. The activities are *generate*, *evaluate* and *select*, which are used to solve the *issues*, which consist of *problems, requirements, function, concept and detailed design*. Blessing uses a *Product hierarchical tree* in the *Product Model* module (of PROSUS) to relate the *design matrices* of product, assemblies, standard component or components. The relationships between these are stored as a *relationship model*. The design matrices are placed at the nodes of a *Product Hierarchical Tree.* Apart from hierarchical relationships, several other relationships, such as spatial or functional, exist between product elements. The relationship model represents the product elements, their relationships and the type of relationship(s). In this model, systemic view is explicit; however, environment is not proposed as an explicit construct.

Pahl & Beitz [20] proposed a prescriptive design approach. In the *task clarification* stage, they prescribe setting up a requirements list based on subsystems. In the *conceptual design stage*, they suggest developing *function structure* (i.e. *a system of sub-functions*) based on the requirements list. For each *sub-function, working principles* should be developed and combined to form *working structures*. Suitable combinations of *working structures* (i.e. a system of working principles) should then be developed and selected to develop *principle solution variants*, which should be evaluated to get a *solution principle* (or a concept). In the *embodiment stage*, with these *solution principles* and requirements list, embodiment determining *main function carriers*, *preliminary layouts* and *form designs* should be developed. The most appropriate *preliminary layout* and *form design should* be developed further. The solutions to *auxiliary functions* should also be developed. Then, *detailed layouts* and *form designs* of the *main function carriers* should be developed, their compatibility with *auxiliary function carriers* checked, and final layout developed to obtain a *definitive layout*. In the detail design stage, details are finalized and detail drawings completed with *definitive layout* as input. These should be integrated into the *overall layout drawings, assembly drawings*, and *parts list*. The systemic view can be seen here at several levels. Within conceptual design is used in *function structures* at function level, and in *working structures* at working principles level. In *function structure*, functions can be seen at system, subsystem, and individual levels. *Working structures* are developed at subsystem and elements level. At the *embodiment stage*, *layouts* are developed at the system level, and *form designs* at the element level. The *drawings* produced are at different system levels. Both *Assembly drawings* and *layout drawings* show system and subsystem level details. *Part drawings* show element level details. Systemic view, although used explicitly in earlier stages, it is not logically extended to, and becomes less explicit in, the later stages of design.

Hubka & Eder [16, Figure 7–3], developed a model of designing with their theory of technical systems. In this model, outcomes produced at each level of abstraction are: 1) p*urpose*, 2) *transformation Process structure*, 3) *function structure*, 4) *organ structure*, and 5) *component structure*. These structures are made of subsystems and elements.

Hubka & Eder [16, Figures 7-12 and 7-13] combine the theory of technical systems (TS) with a design process model of activities and outcomes. The activity 'elaborate and clarify the assigned specification' is performed to develop *design specification*, as a *Transformation Process* [TP]. The activity 'establish function structure – Investigate alternatives' is performed on the TP's to optimize these into one optimal TP on which the technical system and its boundaries are applied to establish grouping of functions, resulting in *function structures*. The *function structures* are used to develop an optimal *function structure*. The activity 'establish organ structure – Investigate alternatives' is used to develop an optimal *organ structure*. The subsequent activity is 'establish component structure – investigate alternatives' resulting in a *component structure - preliminary layout* which is used in the next activity 'establish component structure.. – investigate alternatives'; this results in a *component structure - dimensional layout.* These are used for the next activity 'establish component structure… – investigate alternatives' which gives *component structure* and *detail drawings.* As can be seen, these 'structures are made of subsystems and elements. However, environment is not used as an explicit evolvable element through the design process.

Chakrabarti *et al.* [6] proposed a prescriptive approach for conceptual design of micro-sensors. The process of designing involves the activities of: *generating a design concept*, *identifying potential behavioral problems* and *trying to fix these problems;* the outcomes proposed are: *functions*, *solution principles* and *embodiments*. The activity cycle is performed on *solution principle* which is one of the outcomes proposed. Chakrabarti *et al.* [6] represent 'function' and 'solution principles' respectively using an input-output description and concatenated laws and effects. This suggests that each function is divided into sub-functions for which solutions are combinations of *elementary devices*. This shows the implicit presence of a systemic view in this model of designing. However, environment is not taken as an element of the systemic view.

French [10] has a descriptive model of designing. The activities are: *analysis of problem, conceptual design, embodiment of schemes, and detailing*. The outcomes are: *statement of the problem*, *selected schemes*, *general arrangement drawings*, and *working drawings*. The *selected schemes* are solutions at the system level. The *general arrangement drawings* produced are solutions at system and subsystem levels. The *working drawings or part drawings* are solutions at the element level. The systemic view, however, is not made explicit, not is environment taken as a construct.

Nidamarthi [19] proposed a descriptive model of designing. The model consists of two stages: *problem understanding*, performed on the contents of the design problem, and *problem solving*, on solutions. Under these stages, the activities are sub-divided into primary and secondary activities. *Problem understanding* is sub-divided into *identify* (*perceive, infer, modify*), *analyze* (*question, relate, weigh, verify, visualize*), *choose* (*decide*). *Problem solving* is sub-divided into *generate* (*create, modify, detail*), *evaluate* (*identify characteristic, question, relate, verify*), *select* (*identify things to do, compare, decide*). In this model, the systemic view does not seem to be represented.

Cross [7, pp. 3-11] developed a descriptive model of designing. In this model problems and solutions are developed together. A problem contains goals, constraints and criteria. The solutions developed start as a solution space at the system level, then to system and subsystem levels (i.e. as concept sketch, drawings, and evaluated drawings) to elements level (i.e. in final production documents). Cross *suggests* defining design problems properly, for which he suggests using problem structures (i.e. to subdivide a problem into sub-problems and link these) and decision trees. These seem to underlie an implicit systemic view at the earlier stages of design. Cross explains the three levels of complexity in artifacts: simple artifact with one drawing (e.g., door handle); larger more complicated artifacts which need hundreds of drawings (e.g., whole buildings), and most complex artifacts with thousands of drawings (e.g., chemical plants, aircraft or major bridges). From these examples, it can be seen that some thinking around a systemic view underlies Cross' model, but has not been made explicit.

Cross [7, p. 42] has also developed an Integrative model of designing – which is a symmetrical problem-solution model in which an overall problem is divided into sub-problems, sub-solutions are found, and from these an overall solution is developed. Within this model, seven stages are proposed: 1) *clarifying objectives* 2) *establishing function structures* 3) *setting requirements* 4) *determining characteristics* 5) *generating alternatives* 6) *evaluating alternatives*, and 7) *improving details*. The symmetrical problem solution model indicates an implicit presence of a systemic view in this model.

VDI2221 explained in [7, pp. 38-41] is a prescriptive, systematic approach for designing technical systems and products. The outcomes are at different levels of abstraction: *specification, function structure, principal solution, module structure, preliminary layouts, definitive layout, and product documents*. Systemic view is explicitly used at the second stage of the VDI2221 design process, where functions and a diagrammatic *function structure* are determined. At the third stage, *solution principles* are developed for sub-functions, and combined to form a *principal solution*. At the fourth stage, *principal solution* is divided into realizable modules and *module structure* is developed. At the fifth stage, key modules develop into *preliminary layouts*, which further develop at the sixth stage into a *definitive structure*. In the seventh stage, final product documents are produced. VDI2221 follows a general systematic procedure of first analyzing and understanding the problem as fully as possible, then breaking this into sub-problems, finding suitable sub-solutions, and combining these into an overall solution. The systemic view is explicit in all the stages except the first stage. However, like others described before, environment does not fare as an explicit, evolvable element.

Deng *et al.* [9] propose a function-behavior-working environment-structure model. They argue that the input-output *flow-of-object* is only a physical-level design abstraction, while *flow-of-action* is a functional-level design abstraction, hence *flow-of-action* can capture design intention. They state that system is surrounded by environment which consists of a number of *environmental elements*. Of these environmental elements, some have no interactions with the system, but few elements contribute directly to the working of the system. These are included in what Deng et al. call the *working environment*. They also demonstrate that the information related to *working environment* has great influence on the system's performance.

Bhatta and Goel [3] develop a normative theory of conceptual device design called model-based analogy (MBA). MBA takes a design problem as *functional requirements* and *structural constraints* on the desired design, and gives the outcomes in the form of a *structure* that realizes the specified functions and structural constraints. In addition, MBA gives a Structure-Behavior-Function (SBF) model that explains how a structure realizes a desired function. The structure of a device in SBF models is represented hierarchically in terms of its constituent structural elements and relations among them such as *part-of, includes,* and *parallely-connected.* This points to an implicit presence of a systemic view in the model.

Lossack [18] developed a prescriptive design approach. The activities are: *define problem, find a solution, describe solution, evaluate solution, select solution*. The outcomes are: *requirement, function, physical principle* and *embodiment*. At the *function level,* a *task structure* is used to present the relationships among tasks which build a hierarchy. At the *physical principle level,* a physical solution is described covering all the information of the physical interrelationships of an artifact. Both these levels suggest the presence of a systemic view, by the use of *task structure, physical principle structure* and *geometry structure*. However, the systemic view is not explicit in the other two levels of abstraction: requirement level and embodiment level.

Hansen & Andreasen [14] developed the Domain Theory, in which the mechanical artifact to be designed can be seen in three domains – *Transformation, Organ* and *Part*. In Domain Theory, there are three principal synthesis steps, one in each domain. In each domain there are two types of steps, *detailing* and *concretization*. The outcomes are *the characteristics* in the step of *detailing* and *the values to these characteristics* in the step of *concretization*. These outcomes are present in each domain. Hansen and Andreasen propose to use the Theory of Technical Systems by Hubka and Eder [1988] in each domain.

Hansen & Andreasen [14] combine Hubka's Function-Means law and Domain theory, and use these for design synthesis. The function-means tree divides functions into sub-functions, for each of which, a means is developed. This shows the presence of a systemic view in this approach.

Campbell and Rai [4] develop a prescriptive approach to designing. They propose to use the activities of representation, generation, evaluation and guidance. In the activity *representation,* a wider variety of *candidates* (e.g. a 'problem as a fixed set of decision variables',… or 'grammar or production rules') are developed. The authors suggest *grammar or production rule* for obtaining a wider variety of *candidates,* which are synthesized in the *generation* activity. The next activity is *evaluation* of solutions; based on objective values determined in the evaluation, the activity of *guidance* is used for regeneration or redesign of new and better solutions. It is not clear from the descriptions given, whether a systemic view is implicitly present or not.

Ulrich and Eppinger [25] present a product development process which is a sequence of steps employed to conceive, design and commercialize a product. They also divide a product into functional and physical elements. The physical elements of the product are the parts, components and subassemblies that implement the product's functions. A systemic view, at the structural level is therefore present.

Howard *et al*. [22] combine *modular system hierarchy* and *design activities process*. They propose that a design process should refer to the types of activities carried out when a design task, and is independent of the systems level at which the task is set. They argue that the four stages, *analysis of the task*, *conceptual design*, *embodiment design*, and *detailed design*, form the *design activities process*. In the modular structure hierarchy a machine, product or artifact is broken down, typically from overall system to subsystem, to parts and components. In this view, the systemic view is taken as a explicit, separate dimension of the design process.

2.6 Major findings from literature survey

The following are concluded from the literature survey [Refer to Table 1]:

1. Review of literature on design models shows the following: some models consider systemic view implicitly, for example French [10], while others consider this explicitly, for example Blessing's [2], Hubka and Eder [16], and Howard et al. [22].
2. Environment is explicitly considered in very few models, e.g. Deng *et al.*[9] and Hubka and Eder[15].
3. The models rarely consider 'environment' as an evolvable construct.
4. Co-evolution of system and environment during the design process does not seem to have been discussed before in design models.

Table 1 Systemic and Models of designing

Literatures	**SystemicView Explicit[E] or Partially-explicit[PE] Implicit [I]**	**System**	**Subsystem**	**Element**	**Environment**
[1]	E	System	Subsystem, Components	Parts	Environment
[12]	E	System	Subsystem	Objects	Environment
[8]	-	-	-	-	-
[11]	I	System	-	-	-
[26]	I	Problem Solution	Sub-problems	Intermediate solutions	-
[2]	E	Product	Assemblies	Standard components or components	-
[20]	PE	System, Black box, Function Structure(overall function), Solution principle, Assembly drawings, Layout drawings	Function Structure (subfunctions), Working Structure, Layout Drawings, Assembly drawings	Function structure, Working structure, Form designs, Part drawings	-
[16, Figure 7–3]	E	System	Subsystem	Elements	Environment, Active Environment
[16, Figures 7-12 and 7-13]	E	System	Subsystem	Elements	Environment, Active Environment
[6]	I	Functions	Sub-Functions	Sub-functions, Elementary devices	-
[10]	I	Selected schemes, General arrangement drawings	General arrangement drawings	Working or part drawings	-
[19]	-	-	-	-	-
[7, pp. 3-11]	I	Solution space, Concept sketch, Drawings, Evaluated drawings	Concept sketch, Drawings, Evaluated drawings	Final production documents	-
[7, pp 42]	I	Problems Solutions	Sub problems Sub solutions	Sub problems Sub solutions	-
[7,explained in pp 38-41]	E	Functions, Function structure, Principal solution	Sub-functions, solution principles, module structure, preliminary layouts, definitive structure, sub-problems, sub-	Sub-problems, Sub-solutions	-

			solutions		
[9]					Environment, Working Environment, OBPs
[3]	I	Refer to Section 2.5	Refer to Refer to Section 2.5	Refer to Section 2.5	Refer to Section 2.5
[18]	PE	Task structure, Physical principal structure, geometry structure	-	-	-
[14]	I (they *only* stress the use of Theory of technical systems)	System	subsystems	elements	Environment, Active Environment
[14]	I	Functions	Sub-functions, Means	Sub-functions, Means	-
[4]	-	-	-	-	-
[17]	E	System	element or segment, subsystem, assembly, subassembly	components and parts	
[22]	E	Machine or product or artifact (Overall system)	Subsystem	Parts and components	

3. Validation of Systemic View using Design Protocols

In order to validate the importance of incorporating a systemic view in design models, we analysed protocols from a series of design sessions. The intent was to check whether or not these constructs of the systemic view proposed are naturally present, albeit implicitly, in these design sessions.

Three designing sessions are used for validating this extended model. Three designers [D1, D2 and D3] of varying background and experience were each given one problem brief from two product design problems [P1 or P2], see Table 2.

Table 2 Pattern of Problem-Solving

Problem brief	D1	D2	D3
Designer	P1	P1	P2

Each design session consisted of an individual designer solving a design problem under laboratory conditions. The design sessions were video and audio recorded and each session was assisted by a researcher for clarification during the session. The designers were instructed to **think-aloud**, without any restrictions on time. The problem briefs are:

P1: **"***India has large number of people with transferable jobs. They need to shift frequently from one place to other (every 1-2 years). And often face problems transferring present types of furniture, which are bulky and heavy. It is not economical for them to buy furniture and sell it before shifting to other place. This furniture occupies lot of space and this is an additional problem since they live in small houses. It takes more time to pack the furniture and it damages during transport if it is not packed properly.*

Your task is to design portfolio of furniture which ***will help in sleeping and storing things*** *while taking the above problems mentioned. Setup time and effort on the part of user should be minimal.*

At the end of the design you are expected to provide drawings and a bill of materials and any other detail necessary for the production of the product. You may consider all the life cycle phases of the device/product for your design.

Life Cycle Stages

*Every product/device passes through several stages in its life from birth to death. These are called product life cycle stages. The following are some of the main life cycle stages of a product: Raw material, Production, Distribution, Usage and Afteruse.***"**

P2: (is different in only one part) **"***Your task is to design portfolio of furniture which* ***will help in sit, write and eat*** *while taking the above problems mentioned. Setup time and effort on the part of user should be minimal.***"**

The transcriptions of the designing sessions were available from earlier research. These transcriptions along with the problem briefs, sketches, and videos and audios of the designing sessions were collected. These transcriptions, videos and sketches were analyzed by coding the transcriptions using the following constructs, which together represent the systemic view:-

1) System – S
2) Subsystem – SS
3) Element – El
4) Environment – Env

Some examples of the above constructs are as follows:
System – A designer says: *“i have basic chair(System) would be i am making one conventional chair which can help in sit, write and eat that is some where near a dining table”*. In this example, the designer designs a chair which is a solution for all the requirements given (sit, write, eat, easy to transfer) under certain environmental conditions like presence of dining table (for writing and eating).
Environment - A designer says, while reading the problem brief: *“and is additional problem as they live in small houses”*. In this example, the designer considers that the user of the furniture lives in small houses (Environment around the furniture).
Subsystem - A designer says: *“so it (System) again becomes something like a suitcase and plus this retractable lid (subsystem) which will have to carry the rectangular frame kind of thing”*. In this example, the retractable lid is a subsystem that helps in packing the system.
Element – a designer refers to a *“Velcro strip (Element) that can rest on these supports”*.

The results shown in **Figure 5** demonstrate that in each of the three designing sessions analysed, all the constructs of the proposed systemic view were present.

4. Illustration of System-Environment Co-evolution

An example of the System-Environment co-evolution is taken from the session in which D1 solved P1. From the problem brief, D1 found various problems associated with the furniture [i.e., the Existing Systems], two of which are: ‘space for furniture’, ‘unfolding and packing’ as shown in Figure 1.

The problems found were then “analyzed” by D1, requirements were generated, such as these: ‘furniture will be foldable to save space’ and ‘fixed furniture (already)’ [with sub points - ‘modular to save space’ and ‘It can be fixed to slots’], as shown in Figure 1.

From all the requirements prepared, D1 made a list of requirements that he intended to be fulfilled by the system. One of those requirements is ‘foldable and space saving’, as shown in Figure 2.

With the above list, D1 sketched an idea of a piece of furniture (S), see Figure 3. According to this idea, when the user intends to use the furniture (S) as a bed or a storage space, it would be horizontal, but when the user does not use the furniture (S), it could be folded against the wall (Env) to save floor-space (Env). To fold the furniture (S) against the wall (Env), D1 defined the distance between the furniture (S) and the wall (Env); he also defined the relationship between the furniture (S) and the floor (Env) as a ‘hinge joint’ as in Figure 5.
The above example illustrates, that, as design process continued, both the System and its Environment evolved, simultaneously and through mutual influence.

5. Conclusions

The important findings in this work are as follows. Empirical studies show that designers implicitly took into account the system and its environment and changed both as necessary during designing. The literature stresses the importance of the systemic view, which includes environment as a construct, in designing. Literature in design models, however does not consider environment as an *explicit, evolvable* construct in designing. Representing this view as an explicit, evolvable construct, therefore, is necessary for describing system-environment co-evolution. Also, this work empirically shows the presence of the constructs of systemic view in designing, and their co-evolution.

6. Future Work

To strengthen the results of the validation more protocol studies are required.

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Appendix A:

An **activity** is defined as a deed of problem finding and solving [Srinivasan, 2010]. An **outcome** is defined as a property of a design at a particular level of abstraction [Srinivasan, 2010]. A **requirement** is an expression of what a design should have; it can belong to any level of abstraction. A **solution** is defined here as a means to satisfy requirements. **Associated information** is the information, other than the contents of requirements and solutions, communicated through the design problem, colleague or any other source, concerning requirements or solutions [Nidamarthi, 1999].

Appendix B:

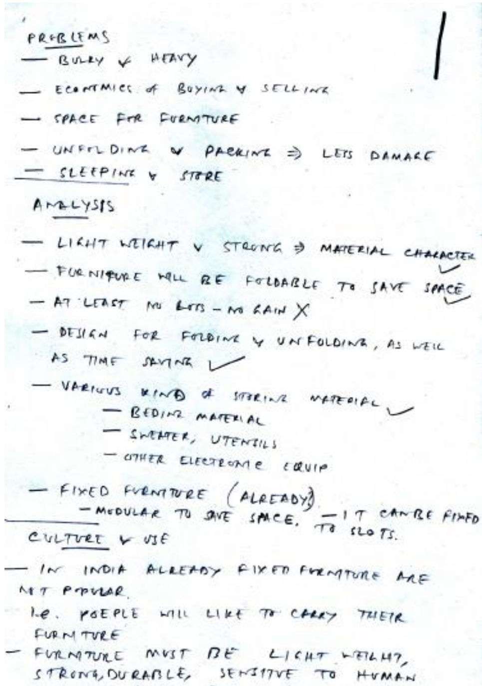

Figure 1

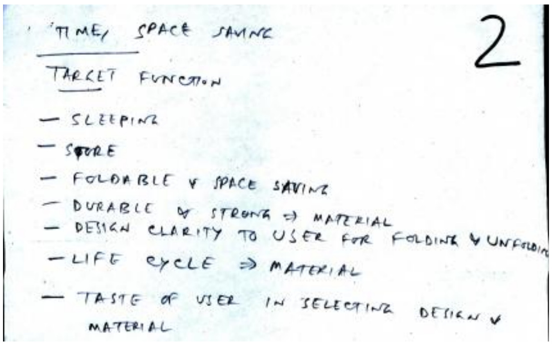

Figure 2

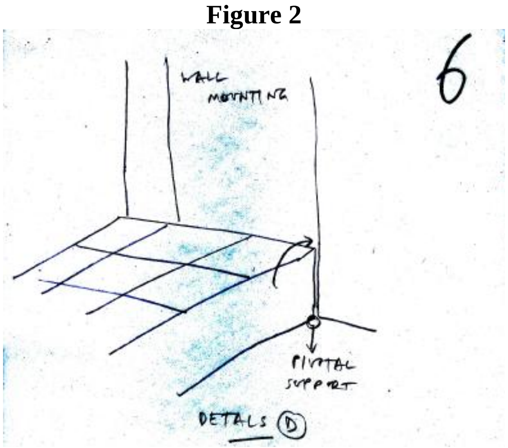

Figure 3

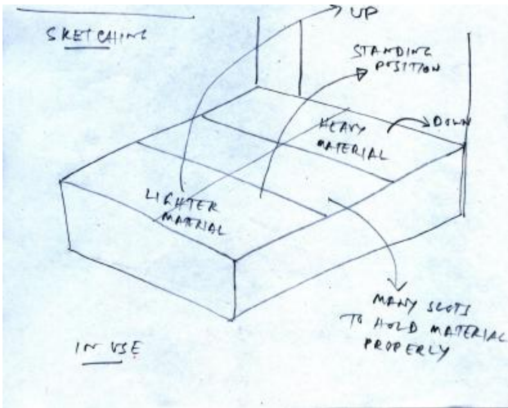

Figure 4

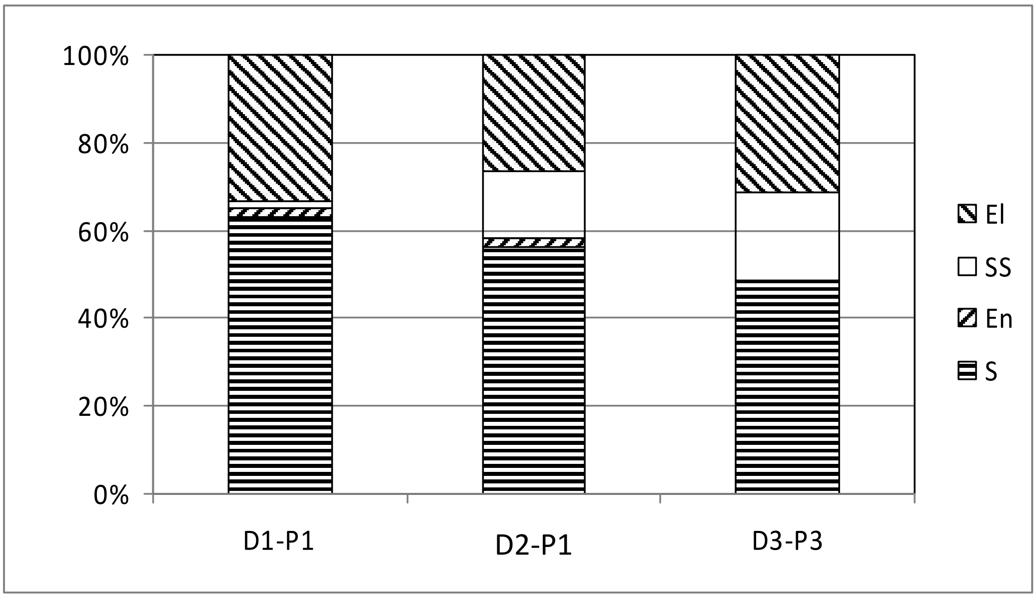

Figure 5 Systemic View