Product Economy through Changing Structural Characteristics

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ABSTRACT
Our aim is to show effects of changing structural characteristics on product design. For this purpose shape, material, structure are observed and evaluated on a specific industrially produced anonymous furniture. This study points to the importance of including structural and material characteristics that is chosen as it exemplifies a typical small-scale design research study. In this study we have handled a particular aspect of design using strain gauge technology and stress analysis methods in the evaluation of product structure. Above mentioned methods can be useful in industrial design objects, signifying the strength of different regions on an object to facilitate decision making for designers. In industrial design strength, material selection and stability of the objects are important properties for the firms' profitability.

Keywords: Design research, design economy, product design, product development, designtechnology.

1.INTRODUCTION
In design we seek to address human experience by improving the artifact like other researchers (Jones, 2014). In a global business environment, innovation, especially product innovation, is prerequisite for market success, and often for the survival of the company (Stevanović, et al 2016). Göran Roos (2016), in his article refers, "the design-based innovation paradigm is increasingly important within the manufacturing industry, but that its benefit can only be maximized if it is integrated with the other three value-creating approaches to innovation." All types of innovation processes involve the diffusion of knowledge about existing problems and research activities, as well as design education, whereby outside-in processes are less critical (Benjamin Knoke, et al 2015) (Berglund and Leifer, 2016).

In this study the notion of design economy on furniture is intended to be improved. Design researchers have used experiments and observational studies extensively over the last forty years to explore the working practices and performance of designers and design teams (Cross, 2007). As Chakrabarti and Blessing (2014:17) say, "…the majority of authors emphasises that value is ultimate purpose that is to create support to improve practice, based on the understanding obtained". "The design economy' represents the economy created by those employed in design roles in a wide variety of industries – from design intensive sectors, such as web design or animation, to designers and design-engineers in automotive or aerospace companies. This means that for the first time our research includes sectors where design is used, but is not the prominent identity" (Design Council, 2016). Design economy has a key role to improve a firm's profitability as Deming (1986) indicated. Our model reveals the major contribution to design of a single product for a firm. Solving the productivity of a firm is one of the biggest questions facing the managers as Albers and Wintergerst refer (2014:153), "Market value of a product often refers to the quality of its functions. Creating these functions by defining appropriate design parameters under technical and economical boundary conditions is a major challenge in the product development process". Average outputs per product in a firm are known as design's role in the firm economy. Our aim is to show a part of this process. As Charles Burnette (2015) indicated in his article *EvaluativeThought in A Theory of Design Thinking* "The systematic framework of A Theory of DesignThinking allows judgment, assessment, and subjective values to be applied to intentions, objects, organizations, ideas, interactions, communications, products, processes, beliefs, learning, self, and society through a common framework. We focus on empirically established evidence through evaluative thought as indicated by Bayazit (2004). There is an ongoing challenge to improve the quality of empirical studies in design research" (Blessing and Chakrabarti, 2009).

Imre Horváth and Zoltán Rusák (2007) in their editorial for *the Journal for EngineeringDesign*, present a general view on engineering and industrial design process: the shape isdefined by technical requirements, functionality, physical principles, structure, ways of materialization, and manufacturing technologies, while for industrial designers it is determined by aesthetics, ergonomics, usability of and experiences with products. Burnette (2016) "This duality gives rise to many challenges when it comes to computer support of shape design and optimization. It achieves this by incorporating specialized evaluative components in the intentional frame used to organize thought or action about anything." We used a computer program to evaluate furniture to acquire and assess to provide useful feedback about it. According to The Web Center for Social Research Methods /Evaluation Research/Introduction to Evaluation (2016) "The generic goal of most evaluations is to provide "*useful feedback*" to a variety of audiences including sponsors, donors, client-groups, administrators, staff, and other relevant constituencies. Most often, feedback is perceived as "*useful*" if it aids in decision-making." "In the theory, the Evaluative mode of thought is understood to address any aspect of our experience, from subjective feelings to life itself, from the selection of the right problem to the appreciation of a painting or validity of a scientific experiment. This broad range of application necessitates that evaluative thought be purposeful and selective about what is evaluated and what criteria are applied" (Burnette, 2015).

We developed a laboratory-based design experiment to explore what methods can be used to improve strength, reproduction and consistency. This study evaluates the effects of structure on industrial designs, in particular furniture designs. Property of structure in furniture design is not generally considered by designers from an engineering perspective (Bayazit, 2011).

As Pine and Gilmore (1999) explained work is theatre in every stage of business. Unfortunately as Stevanovic, et al (2016) said, "Only in a minority of cases there is no formal group and/or individual responsible for the collection and verification of ideas." Our case is one of them.

As Bruce Archer (1981: 30-47) said, "Design Research is systematic inquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value and meaning in man made things and systems." As Vermaas (2014: 47) said. "Design Research is about observing existing and created design practices, about formulating design theory and models." Thuan et al. (2015) refers that "high applicability of design science to emerging areas, finding appropriate design methods that can provide methodical and transparent accounts of researchers' activities is challenging." In this project we tried to find an appropriate method to reach an optimal solution for the structure of simple tubular steel furniture. As Cameron Tonkinwise (2005) stated in his article, *Design + Evolution =Eugenics: Mimetological Analogies, or Why is Design so Enamoured with Evolution?* design's renewed embracing of evolutionary systems must be mindful for further studies as well as industry. Our aim is to develop a renewed evolutionary system for a small object.

Structure has prime importance in architecture and mechanical engineering. Every architectural and mechanical designer should know structural principles, materials as well as their effects on the design. In the design process, mechanical engineers depend on structures, like architects, in their designs. Industrial designers make their designs depending on their experience in the field of their practice not like architects or mechanical engineers. Industrial designers are not aware of the product economy and innovation process in general. The circumstances are not the same with industrial designers while they are working. The concept of structure is not in the curriculum of industrial design education although it is firmly studied in architecture and mechanical engineering. There are very few structural studies on industrial design in particular furniture. We have knowledge of furniture design as we observe actions taken in design practice. Understanding structure helps designers to create new economical designs. Our aim was to clarify industrial designers' role on structure in the development of their designs. We agree with Vermaas (2014:49) "We develop criteria to evaluate design practices, for instance as successful or not, as efficient or not, as innovative or not. We have knowledge of design practices in the form of, say, observed regularities between the action or reasoning of designers in design practices, and the success and efficiency of these practices."

As Peter Jones (2014) tells in his paper "a theoretical context of shared principles and shared methods between systems and design thinking… between design methods and systemic principles are well-supported by current practices and might be developed through applications." In this research project our aim is to develop shared principles and shared methods between system and design thinking.

This research project aims at reaching innovation through form-structure-materials relationship for industrial designers. In this study at first we evaluated various structures in furniture design. Most of the designs in furniture design depend on craft tradition, trial and error methods or designers' previous experiences. Industrial design is not only created in visual but also logical forms. Structure and material are not separated from the design. We are dealing with the following relationships:

- Structure-materials
- Structure-form
- Structure-concept
- Structure-manufacturing

Mindful knowledge structure in design enhances creativity. There are many examples in the design literature. Intelligent management of knowledge economy enhances creativity (Friedman, 2003).

2. STRUCTURE IN INDUSTRIAL DESIGN

There are some requirements in industrial design. These can be grouped as technical requirements, ergonomic requirements and aesthetics requirements (Mayal, 1967). Technicalrequirements consist of structure, production techniques and materials. Technical requirements also relate to aesthetics requirements of an object.

"Structure is an arrangement and organization of interrelated elements in a material object or system, or the object or system so organized" (Oxford English Dictionary, 2015). Every object has a structure system. Structure is the particular collection of parts to make objects to stand without help (Bayazit, 2011:122). In industrial design structure makes objects to stand alone and helps to generate form. Balance, form, construction movement and stability are problems to be solved in structures (Inan, 1998).

In industrial design internal structure relates to firmness, functionality, suitability to materials and construction and, finally aesthetics (Ertas, 2007). Form is basic visual quality of designs. Form is composed of one or more materials. Form or design is not only composed of materials but also structure system that makes it to stand alone. A structure is the collection of different parts and their combinations with some joints which plays a role in the transmission of loads to other parts.

3. DETERMINANTS ON THE DESIGN OF FURNITURE STRUCTURE SYSTEMS IN INDUSTRIAL DESIGN

Determinants of furniture structure system are function, form, modularity, material, production system and texture. *Form* cannot be separated from the structure. Efficient relationship between *function, form, material* and *production system* facilitates to create admirable products. Every design is formed in relation to the circumstances and constraints. Form and structure together bring about identity of furniture.

4. METHOD OF THE STUDY

Hevner and Chatterjee (2010) suggest that design science research can be rigorously founded on three types of knowledge sources: 1) scientific theories and methods; 2) experience and expertise; and 3) meta-artifacts. We reviewed different theories and methods relevant to this project at the initial stages. We used an existing product depending on the experience of a firm in the market. Then we created a meta-artifact. This type of study must be a routine work in an industrial firm (Figure 1). Deken et al (2016), in their article "Generating Novelty Through Interdependent Routines: A Process Model of Routine Work" studied routine work to minimize disturbances to customer. Design research and especially practice have a significant component of reflection-in-action (Schön, 1983). Results of design research reflect in our action on furniture design.

We intended to show design economy on ordinary anonymous furniture taken from the market, which is sold extensively. Designer of the product is not known. We chose metal furniture which has hollow tubular steel structure.

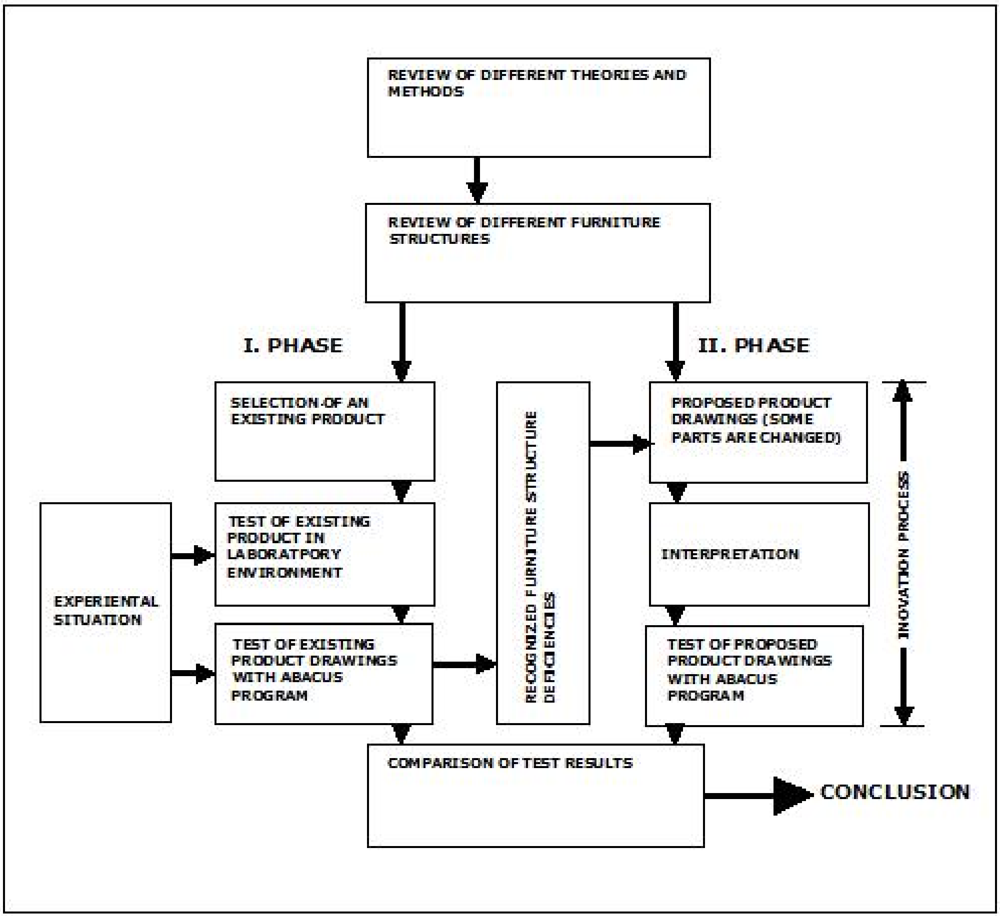

Figure 1 Summary of the general methodology

We approach industrial design empirically. In summary we organize real life experiments on real furniture and then we make a model of this furniture to execute computer simulations.

Computers are limited at supporting changes in the topology of models that are beyond the scope of dimensional variations, performing rapid evaluations based on heuristics with partial information, and representing the diverse nature of the elements of a design domain in the same environment (Bernal et al 2015). Our aim was to forecast and develop new product for traditional productivity with recognized furniture deficiencies.

5. PHASE I

In this study we use form changes in product through the analysis of strains. Strain gauge analysis can be used for different purposes (Ertaş and Bayazit, 2006). In different designs in relation to functional expectations from it and their structural behavior varies. Tubular steel design requires lightness and resistance to crashing, and material economy. Simplifications are useful only up to a point. We were careful not to reduce their utility.

We chose the bonded metallic strain gauge to measure the strains in the selected furniture (Figure 2). Strain gauge is not only used for measuring strains but also used for sensing extremely small changes in resistance, force, pressure, heat, etc. (Khan, Wang, 2001). Strain gauge technique is used to measure strains on the tubular steel furniture. Typical bonded foil strain gauge is used. Furniture must be designed considering their structure as well. From the economical point of view, reducing the weight of furniture makes a big difference in the initial cost of the furniture. Strain gauge principles are known in many engineering disciplines.

At first we tested the strength of furniture in a laboratory environment. To test performance of existing furniture, we decided to apply strain gauge experiments on it. To develop furniture structure test method, strain gauge technique is applied to understand form deformations of products under different load pressure in the laboratory environment. When human loads or any other loads are applied to metal furniture, we can measure stress and strains in tubular steel as the deformation that occurs.

To measure strains causing changes in length and comparing it to the original length of the load-bearing tubular steel furniture, optical sensors are used under laboratory conditions. Wire as well as foil strain gauges are used on the strained surfaces. Strain gauges are used that are carefully bonded to the tubular steel surfaces by a thin layer of epoxy resin. It was a short duration of use and temperature variation was not a serious problem. Stress is defined as the object's internal resisting force, and strain is defined as the displacement and deformation that occur.

5.1. Working Principles of Strain Gauge

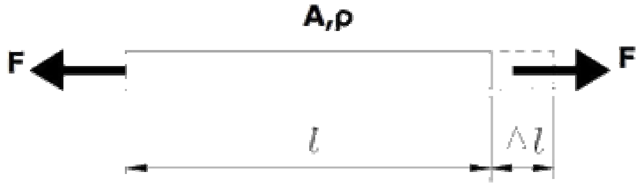

Figure 2 Working principles of strain gauge

For a strain gauge, displacement (change in length, *l*) due to a force F is related to the change in resistance, ΔR, by the following expression (Fig.2)

$\frac{dR}{R} = K\varepsilon$ □□□□□C□1□2□□□1□2□□ $\frac{\Delta L}{L}$ or briefly $\frac{dR}{R} = K\varepsilon$ is obtained, where K is a material constant, called gauge factor, C and □□□ being related to the change ininternal resistance ρ and other strain gauge properties, and$\varepsilon = \frac{\Delta L}{L}$

Using these relations, changes in strains are measured so that form changes will be understood. Tensile as well as compressive strains are measured in this study. Strain gauges measure changes in tubular steel (through inductance, or resistance) the strain experienced by the sensor. Bonded resistance strain gauges are used which consist of very fine metallic wire and foil types; they are bonded by a thin insulated layer of epoxy.

Computer simulations are also applied on the selected furniture using ABACUS program. Parts of structure are simulated with 3D wireframes and under the load weight, their performance are examined.

5.2. Recognized Furniture Structure Deficiencies

We have made interpretations depending on the results of analysis.

Weak sections on the structure: The curved sections of the legs changed shapes underexcessive loads. When we sit back on the chair shape deformation on the curved legs of it is less than direct load on the chair. The frame structure of the chair is durable enough. Types of steel, high creep value, use of enough number of parts, and the size of profile are the result of durability of the legs.

Sections with no problems: The structure of the chair is resistant against form changes aswell as loads coming from different angles. The structure of the chair is tubular steel and the seating surface is a membrane which makes the chair light and elegant. Frame under the seating place is supposed to take heavy load and strain. In this area there are more than necessary parts as understood from the distribution of loads on the parts. Reducing some parts from that area means thousands of parts in the production in the industry. Therefore, reducing number of parts or using smaller section of some parts helps product economy.

Structural material: The analysis on the steel structure of the chair shows that resistance ofthe material to breaking under tension is very high. This quality of the frame causes no damage on the frame.

5.3. Analysis of an Existing Structure Design

Selected steel frame furniture is made of tubular steel and leather covered seating elements (Figure 3). Steel frame structure is strong and light, easy to use and produce. Steel frame structure is its dominant characteristic. At first we modeled furniture structure in Abacus computer program and analyzed after loading 120 kg weight to see the distribution of strains. After this analysis we bounded strain gauges on the furniture legs as presented in the following picture (Figure 4) with their codes: A2, T1, A5, K2, D1, T2, K1, A6, A3, A1. We loaded different weights on the chair (Figure 5), (Figure 6) and observed the form and length changes of the tubular steel (Figure 7). We stick one strain gauge to the points having single direction form changes, and at the points three axis form changes points three axis strain gauges are stick.

Microstrains on the structure form changes are calculated with the following formulas:

$$\sigma = \frac{F}{A} + \frac{M}{I} \qquad \sigma = \varepsilon \,.\, E$$

ε is changes in the unit size, σ is strain, E is elasticity module. In the following tables strain values are displayed. 1N = 10 kg, 1 N/mm^2=1 MPa (Megapascal)

Elasticity module of the steel is 2.1x10^5 N/mm^2=2x10^7 N/cm^2 =2.1x10^6 kg/cm^2

Creep strength of the spring steel is 700- 800 N/mm^2

Admissible stress for steel is 14000 N/cm^2 = 1400 kg/cm^2

Strain values calculated according to formula, when calculation of form changes obtained 302 microstrains.

σ=302.10-6x2.105 N/mm^2 (Microstrain 10-6)

σ=60.4 N/mm^2 =60.4 MPa

(-) values are pressure values in Table 1. A2, T1, A5a, A5b, A5c are under pressure. Strains at point A2 is (-) and its pressure value. When we loaded 120 kg at the backside of the chair (Figure 8), strain value is -302 Microstrain (Table 1). At the same point depending, on the normal strains is calculated as -60.4 N/mm^2 (Table 2).

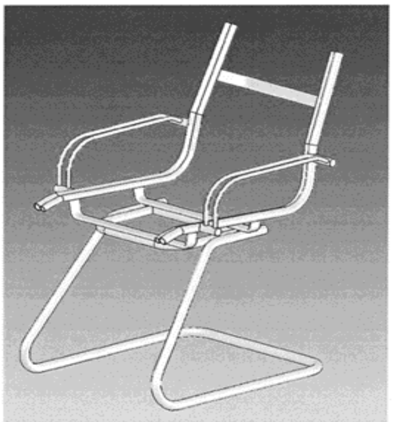

Figure 3 Existing chair structure

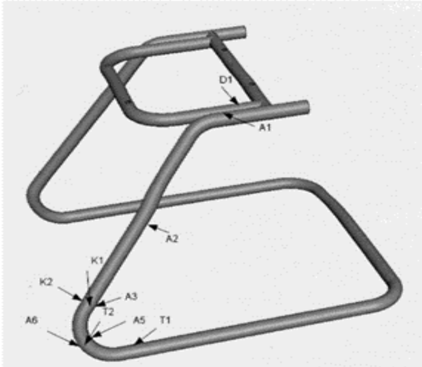

Figure 4 Strain gauge application points on thebase of existing structure

Table 1. Form changes at various points (Microstrain)

Meas ure-ment points	*1. 120 kg strain measure-ments (N/mm^2)*	*2. 120 kg strain measure-ments (N/mm^2)*	*3. 120 kg strain measure-ments (N/mm^2)*	*4. 100 kg strain measure-ments (N/mm^2)*	*5. 100 kg strain measure -ments (N/mm^2)*	*6. 100kg strain measure -ments (N/mm^2)*
A2	-60.40	-285.60	-247.80	-210.80	-204.00	-170.00
T1	-97.00	-350.20	-305.60	-258.80	-216.6	-214.00
A5a	-39.76	-115.52	-297.40	-86.20	-238.00	-63.52
A5b	-132.20	-385.60	-321.20	-290.60	-267.80	-211.20
A5c	-89.80	-236.00	-207.20-	-176.40	-172.00	-126.40
K2	+107.60	+334.80	+298.40	+249.80	+255.00	+210.00
D1	-126.80	+139.00	+93.80	+84.80	+64.80	+38.00
T2a	+27.00	+65.48	+111.00	+51.80	+79.60	+40.36
T2b	+38.60	+98.40	+89.60	+79.40	+63.20	+62.20
T2c	+80.00	+211.00	+209.60	+167.00	+153.60	+127.80
K1a	+29.20	+69.92	+179.60	+53.64	+86.20	+41.32
K1b	+49.20	+124.00	+103.60	+93.00	+130.80	+73.60
K1c	+76.40	+169.00	+156.00	+134.00	+128.00	+106.60

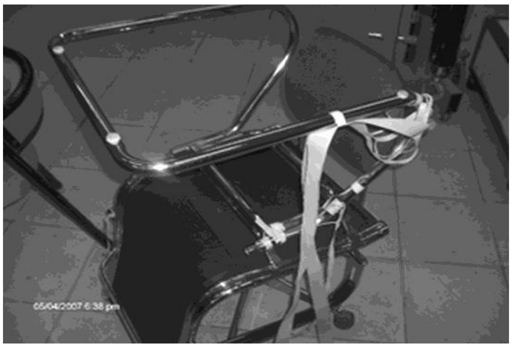

Figure 5 Connection of electrical cables to strain gages

Figure 6 Digital strain gage measurer and cable connection machine

Table 2 Values obtained by strain gauge measurements of existing chair (N/mm^2).

Mea sure - men t poin ts	*1. 120 kg strain measure -ments (N/mm^2)*	*2. 120 kg strain measure -ments (N/mm^2)*	*3. 120 kg strain measure-ments (N/mm^2)*	*4. 100 kg strain measure-ments (N/mm^2)*	*5. 100 kg strain measure-ments (N/mm^2)*	*6. 100kg strain measure-ments (N/mm^2)*
A2	-60.40	-285.60	-247.80	-210.80	-204.00	-170.00
T1	-97.00	-350.20	-305.60	-258.80	-216.6	-214.00
A5a	-39.76	-115.52	-297.40	-86.20	-238.00	-63.52
A5b	-132.20	-385.60	-321.20	-290.60	-267.80	-211.20
A5c	-89.80	-236.00	-207.20-	-176.40	-172.00	-126.40
K2	+107.60	+334.80	+298.40	+249.80	+255.00	+210.00
D1	-126.80	+139.00	+93.80	+84.80	+64.80	+38.00
T2a	+27.00	+65.48	+111.00	+51.80	+79.60	+40.36
T2b	+38.60	+98.40	+89.60	+79.40	+63.20	+62.20
T2c	+80.00	+211.00	+209.60	+167.00	+153.60	+127.80
K1a	+29.20	+69.92	+179.60	+53.64	+86.20	+41.32
K1b	+49.20	+124.00	+103.60	+93.00	+130.80	+73.60
K1c	+76.40	+169.00	+156.00	+134.00	+128.00	+106.60

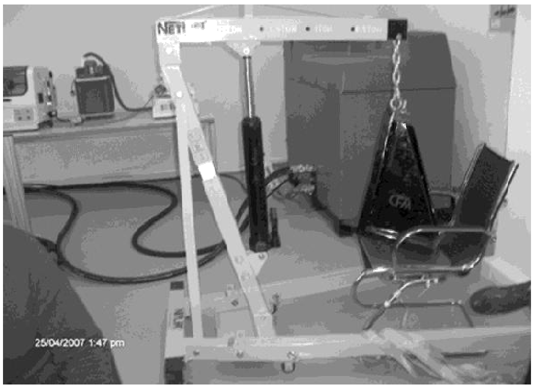

Figure 7 120 kg load on seating surface. 1st measurement

Figure 8 120 kg load on backside of the chair 2nd and 3rd measurements

Table 3 Computer simulations of strains obtained through test on existing chair.

Measurement points	*Strains under 120 kg load*	*Strains under 180 kg load*	*Strain difference at laboratory strain gauge measurements σ (N/mm^2)*
A2	103.43	157.70	60.40- -285.60
T1	78.38	120.18	97.00-350.20
A5	294.88	452.56	132.20-385.60
K2	211.03	322.79	107.60-334.80
D1	69.31	103.701	38.00-139.40
T2	300.42	463.007	38.60-98.40
K1	55.19	85.31	49.20-130.80
A6	275.92	423.25	-
A3	147.86	225.14	-
A1	23.64	35.24	-

Potential roles of computers in the design process, identifying some of the circumstances in which computers are effectively contributing to this process, and visualizing future areas of research that could further support designers' needs are mentioned (Bernal et al 2015:167). They continue "While co-evolving problems and solutions, designers use conjecture and tentative solutions as means to better understand the nature of the problem. Tentative solutions often expose hidden aspects and trigger the redefinition of the problem, which implies that the solution must be adapted to new conditions." Computer simulations of strains obtained through test on existing chair (Table 3).

We made finite element analysis on the same furniture structure. Creep strength of furniture material is 800 N/mm^2, elasticity module is 2.1x10^5 N/mm^2 and admissible stress is 14000 N/mm^2 in laboratory measurements (Table 1). Strain values at point A2 are between σ =-285.60 N/mm^2 and σ =-170.00 N/mm^2. As these values are below the creep strength of steel that is used in design, point A2 is within the normal limits.

Strain values at point T1 are between σ =-350.20 N/mm^2 and σ =-214.00 N/mm^2 (Table 1). These values are also below the creep strength of furniture material (800N/mm^2), elasticity module (2.1x10^5 N/mm^2) and admissible stress (14000 N/mm^2). There are no form changes and no structural problem is observed at point T1 (Figure 9).

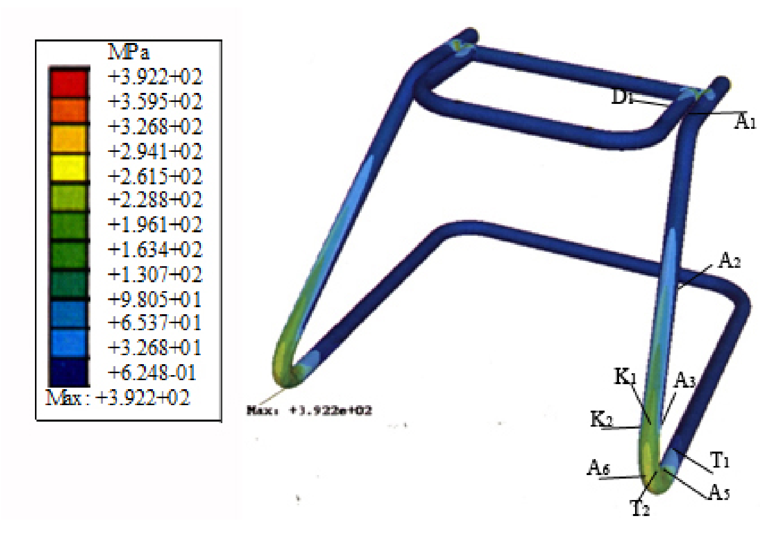

Figure 9 Strains on the existing chair

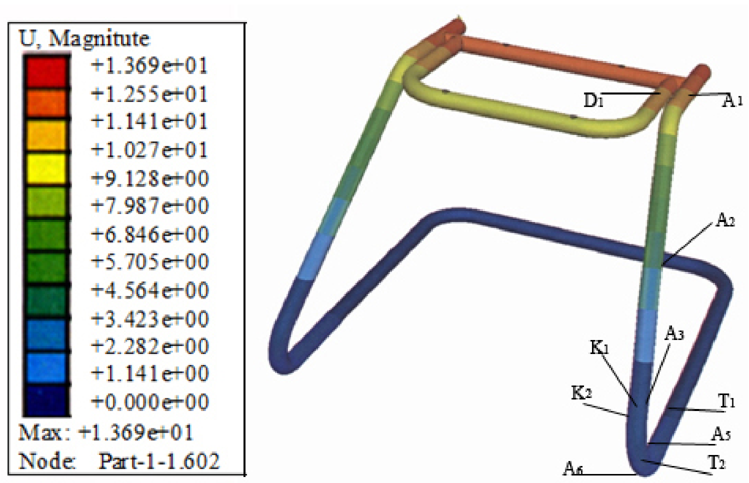

Figure 10 Form changes and displacement values on existing product

At point A5 on the back part of the furniture under no load strain value is σ =-39.76 N/mm^2 and loaded strain value is σ =-115.52 N/mm^2 (Table 2). The reason of increase in the strain value is the changes in the center of gravity (Figure 10). Normal strain is between σ =-115.52 N/mm^2 and σ =-63.52 N/mm^2 (Table 2). There is no problem with the back part of the furniture as it stays below the creep strength, elasticity module and admissible stress values. When A5b is loaded along with principal axis, strain takes σ =-385.60 N/mm^2 and σ =- 211.20 N/mm^2 values. When no load is put on the back side of the chair, at A5c point strain is σ=-89.80 N/mm^2 and strain is between σ =-236.00 N/mm^2 and σ =-126.40 N/mm^2 (Table 2). These results show that the values are below the yield point at A5 and there is no deformation on the tubular steel (Figure 11).

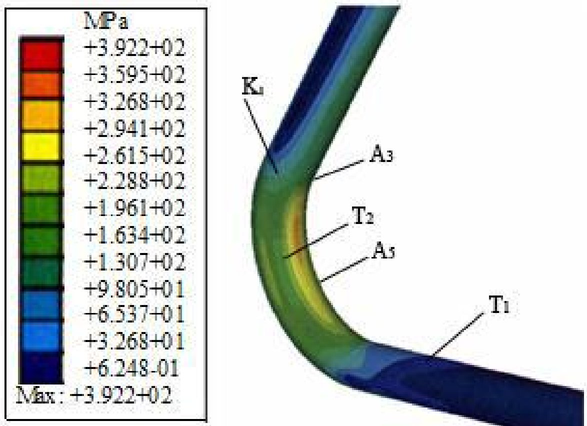

Figure 11 Strains at points A3, A5, T2, K1, T1 existing chair.

When resting on back part of the chair, according to various loadings at point K2 strain values change between σ =+334.80 N/mm^2 and σ =+ 210.00 N/mm^2 (Table 2). There is no problem with the creep strength and elasticity module. Without loading D1 strain is calculated as σ =+-126.80 N/mm^2, it takes σ =+139.40 N/mm^2 and σ =+38.00 N/mm^{2}values, when resting on someone to the back side of the chair. These values are below the admissible stress and creep strength values. Loading the back part of the chair, strain at T2a is between σ =+ 65.48 N/mm^2, and σ =+40.36 N/mm^2; strain at T2b varies between σ =+98.40 N/mm^2 and σ =+ 62.20 N/mm^2; strain at T2c is between σ =+211.00 N/mm^2 and σ =+127.80 N/mm^2. Although these values at point T2 cause bending, elliptical section, these deformations has no negative permanent consequence on the structure because these are below boundary limits.

Without loading back of the chair strain values are for K1a σ =+29.20 N/mm^2, for K1b σ =+49.20 N/mm^{2}and for K1c σ =+76.40 N/mm^2. When back of the chair is loaded, strain values are for K1a between σ =+69.92 N/mm^2 and σ =+41.32 N/mm^2, for K1b between σ=+124.00 N/mm^{2}and σ =+73.60 N/mm^2 and for K1c between σ =+169.00 N/mm^2 and σ=+106.60 N/mm^2. All of these values are below creep strength value σ =+800.00 N/mm^2. These strain values can be evaluated as higher compared to other chairs. Here tubular steel is used, which is strong enough to meet the strains.

6. PHASE II

Experts have the ability to conceptualize the design situations, identify the underlying principles behind the problem, redefine the problem, and reuse their experience to rapidly generate possible matching solutions. Depending on the analysis, it is possible to make changes on this structure. The criteria list for the new structure is in Table 3. Analysis gives us insight about the weak and strong parts of the structure. Therefore, following these experiments a new structure is proposed in Figure 12 and Figure 13, extracting some parts from the seat and adding lighter sheet iron parts. Three actions that expert designer execute during the generation of such solution have been identified (Bernal,2015). They seem to be able to follow parallel lines of thought by producing a range rather than a single solution, integrating knowledge from different fields, and evaluating preliminary solutions (Cross, 2004). This is true for our research. We neglected several alternative solutions depending on the above mentioned criteria.

<u>*Determination of structural material*</u>: Analysis of strain values shows that without changingvisual design of the frame some changes can be made on the frame. Here we propose the changes in the outside diameter of the tubular steel frame from 25 mm to 21 mm, depending on our analysis of strain measurements.

Table 4 Criteria for the development of proposed structure

a.	To reach proposed characteristics in the structure of the design		
	a.1.	Design economy	
	a.2.	Lightness	
	a.3.	Ease of use and performance	
	a.4.	Long life	
	a.5.	New functions	
	a.6.	New appearance	
	a.7.	Strength of materials	
b.	Development of design structure and removing structural problems		
	b.1.	Material studies	
		b.1.1.	Selection of appropriate material
		b.1.2.	To achieve precise use of material
		b.1.3.	Optimization of material and part use
		b.1.4.	Sizing of the structure
	b.2.	Studies on production	
		b.2.1.	Studies on production
		b.2.2.	Development of attachment details
		b.2.3.	Establishment of right relationship between production and structure
	b.3.	Reduction of workmanship	
		b.3.1.	Removing physical failures
		b.3.2	Development of structural form

		.	
		b.3.3.	Development of structure in relation to function
		b.3.4.	Organization of relations between the parts

On this new structure same experiments are conducted to observe whether there are problems on the critical points of the sheet iron. In the Abacus program new structure is loaded and the strains are calculated on the same points tested in the laboratory depending on the criteria list indicated in the Table 4.

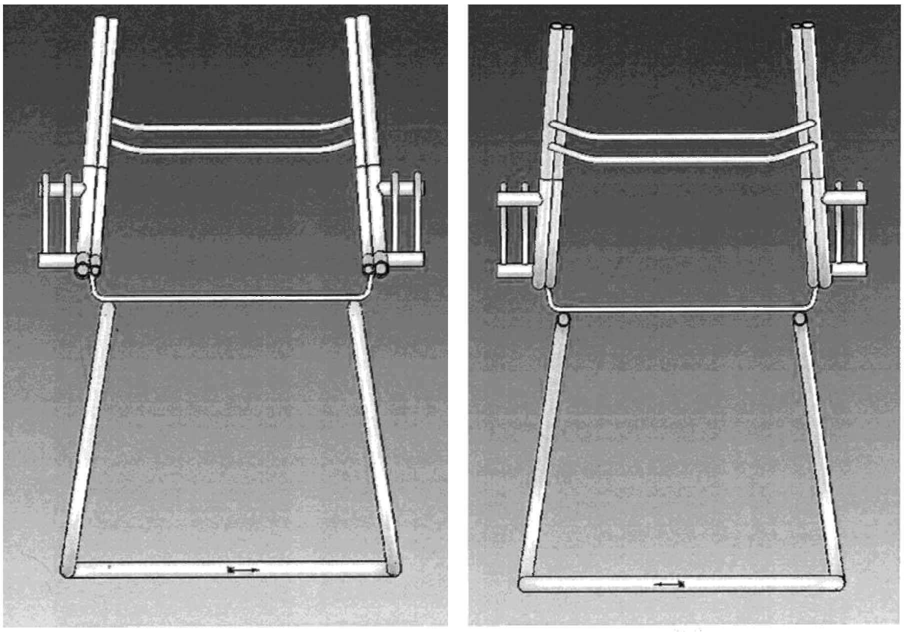
(a) (b)

Figure 12 Front (a) and back (b) views of proposed new structure.

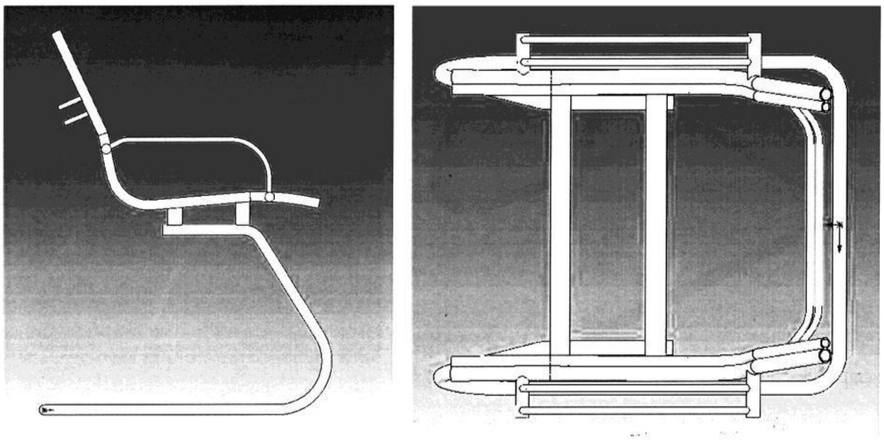
(c) (d)

Figure 13 Elevation and top views of proposed new structure.

Strains are measured on the horizontal two sheet iron parts of the recommended structure. The lowest and highest strains were between MPa=24.652 and MPa=195. 263. Strains in the middle part of the horizontal flat part were between MPa=97.771 and MPa=195.263 (Figure. 14). On the outside of curved part of tubular leg of the chair, strains were between MPa=97.771 and MPa=292.755 (Figure. 15) and on the inside minimum strains were between MPa=0.279 and MPa=292.755 (Figure. 16). In Figure 15 and Figure 16 strains on the middle axis of the curved part was between MPa=73.398 and MPa=292.755.

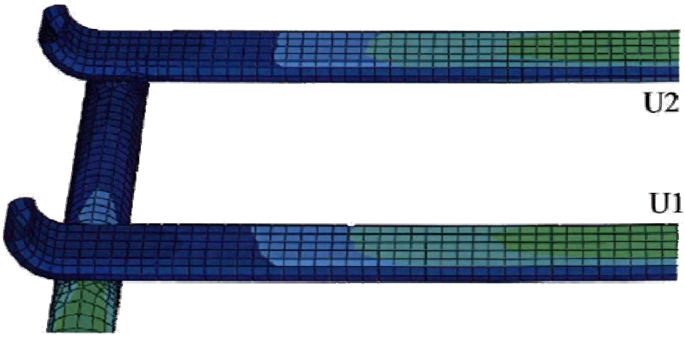

Figure 14. Strains (Gauge factors) on the upper part of the proposed structure.

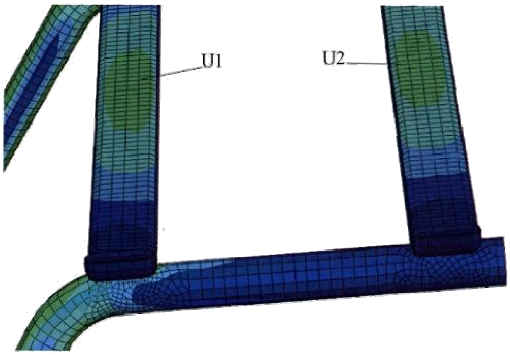

Figure 15 Strain on the upper part of the proposed frame structure. U1 is on the middle offront sheet iron, U2 is on the middle of back sheet iron.

Table 5 Computer measurements on the points of recommended structure for the heaviest persons calculated by the Abacus program 1 MPa (=1 N/mm^2)

Measurement Points	*Strains under 120 kg in the computer program MPa=1 N/mm^2*	*Strains under 180 kg in the computer program MPa=1N/mm^2*
A2	296.568	278.29
T1	64.72	94.66
A5	282.136	420.63
K2	263.773	394.116
T2	115.276	172.44
K1	69.333	103.81
A6	296.568	440.92
A3	235.355	351.152
A1	61.92	92.954
U1	105.88	159.98
U2	104.70	158.15

Table 5 is prepared depending on the strains measured in the computer program. Additional U1 and U2 measurement points are in the middle of the two sheet iron parts (Figure 14 and Figure15).

When we load 120 kg to the structure, strain at A5 is MPa=282.136, at T2 MPa=115.276, at A6 MPa=296.568, at T1 MPa=64.72, at K1 MPa=69.333, at K2 MPa=263.773, at A3 MPa= 235.355 are calculated (Figure 16 and Figure 17). All of these values are below creep strength value σ = + 800.00 N/mm^2. There is no problem with the strains on the proposed new structure.

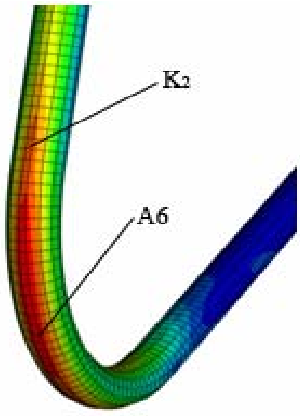

Figure 16 Strains (Gauge factors) on theexternal surface of the proposed frame structure (Points K2, A6)

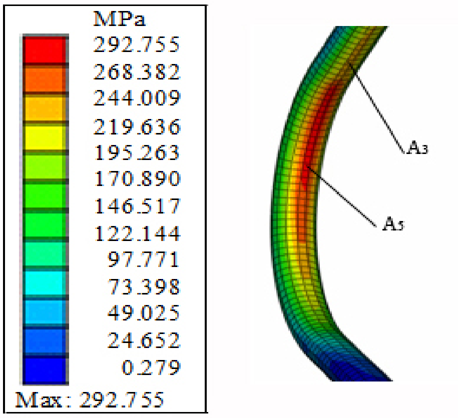

Figure 17 Strains (Gauge factors) on theInternal surface of the proposed frame structure (Points A3, A5)

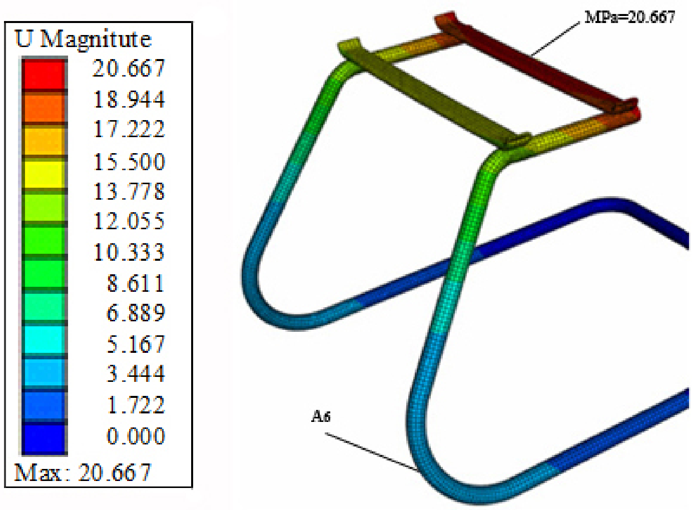

Figure 18 Form changes and displacement values of the proposed structure under load.

Depending on the computer tests made on the proposed structure strain at points A6 is MPa=6.889 (Figure 18). Strains were calculated at point U1 MPa=105.88 and point U2 MPa=104.7 of these flat pieces and curved tubular parts (Figure 14 and Figure 15). These values are below creep strength value σ =800.00 N/mm^2.

Critical strains can be observed from the table near the Figure 15 and 18 as between MPa=73.398 and MPa=195.263.

7. RESULTS OBTAINED ON THE PROPOSED CHAIR STRUCTURE

Depending on all the measurements gauge factors of the proposed structure are always below the creep value. There is no strength problem with the proposed structure. In the proposed structure, we reduced the number of parts and it did not have an effect on the appearance of the chair. Reducing parts generally helps to reduce initial cost of the product. Also, product becomes lighter and duration of production process is shortened. The results are as follows:

- The curved legs of the chair take highest strains and deformations. All parts of the chair are below the creep value of tubular steel structure.
- Reducing number of parts, also removes the welding in four points. Reducing parts helps to reduce duration of production process.
- Strength of structure gives designer chance to make changes on the structure of the chair without changing the external image.
- These values are obtained through physical as well as computer analysis.
- Existing structure has Ø 25mm and proposed structure has Ø 21mm. This change makes the product much lighter.
- Proposed structure has two parts less than existing structure. Reducing number of parts helps to reduce material use, to reduce initial cost of the product and to reduce working hours.
- Existing structure is 13 kg, while new one is 9 kg. This result in the proposed structure is obtained by having smaller section of tubular steel and reducing number of parts. Lightness in design facilitates to carry the product easily.

8. CONCLUDING REMARKS

Product economy is important in industrial design. Product economy can be obtained reducing material use, reducing workers time in production, by the right use of material, good design, right solution to products. Quantity of material used is very important. Manufacturing technology and machine technology is important in industrial design. Reduction in number of parts as well as product sections brings economy to the firm. Semi-skilled workers produce tubular steel furniture, without any calculations on the structure system. Their approach to design depends on common sense and trial and error. Experimentation, models and simulation on design will be useful for future orientation and forecasting. Careful and efficient use of material resources will help economy in expenditure or as a means of saving efficient and concise use of material as well as nonmaterial resources. Products must meet expectations of the organizations, producers, and users. These requirements create a new circumstance for design process and new professional approaches to design practice.

Lightness of product is also important for saving material as well as transportation of the product. Reduction of the parts brings lightness and production time and material savings. Lightness of the product helps users to use product easily. Simple structure solutions make maintenance easy as well as less than complicated ones. Selection of appropriate material solutions either from user taste or manufacturing point of view is important and beneficial for both sides.

Strain gauge tests have valuable results in reducing the cost for manufacturing. There are laboratories in the research centers as well as at the universities to make measurements withtheir personnel. Computer simulations are widely used in many areas by manufacturing companies. Even small producers can use facilities of advanced CAD programs to obtain better results. In industrial design education CAD/CAM programs are widely used. Small traditional companies must have access to these programs for their economical performance.

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Acknowledgements
We used the facilities of two laboratories in our University: Laboratory of Mechanical Engineering and Laboratory in the Faculty of Aeronautics and Astronautics. We got a fund from Istanbul Technical University, Institute of Sciences to promote this research project.