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Evaluation of 3D modeling programs for industrial design use

3B modelleme programlarının endüstri tasarımında kullanım açısından değerlendirilmesi

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Highlights

- *3D modeling programs are investigated in terms of industrial design process requirements.*
- *Related criteria for evaluating 3D Modeling programs are determined.*
- *The use of Analytical Hierarchy Process is investigated.*
- *A model is proposed for performing analytical evaluations in industrial design.*
- *The proposed model is applied on the field study in which selected programs are evaluated.*

Graphical Abstract

In the article, Analytical Hierarchy Process (AHP) which had been used for evaluation purposes in numerous theoretic and practical fields in academic to industrial circles is investigated and the use of the method is explained in detail.

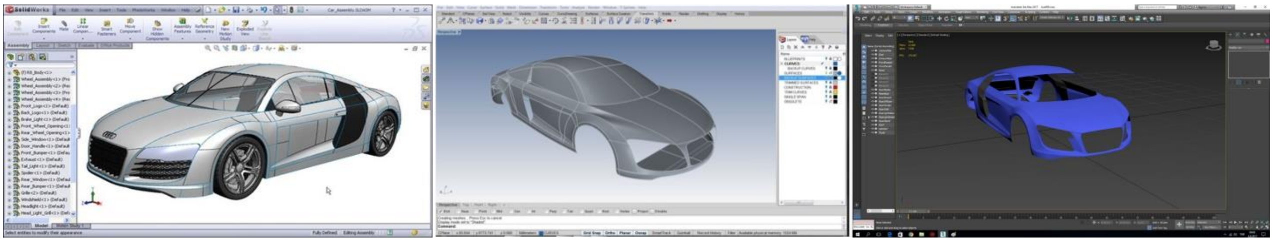

Figure. PC Program Packages (PP) one of which will be selected as the most suitable one for general industrial design use

Aim

It is intended to introduce an analytical evaluation method to industrial design and demonstrate its use and benefits, improving the acceptance of such methods in the field.

Design & Methodology

The research model, based on the AHP method is proposed and explained in detail. Then it is applied in a field study in which 3D modeling programs are evaluated for suitability to the industrial design use. Research data is gathered by interviews and processed with tools given in the article. The findings are presented and interpreted.

Originality

The article is the outcome of an original research on the subject.

Findings

The findings relate to the investigation of the suitability of 3D modeling programs to the process needs, cost/ performance, reliability, technical support and documentation requirements of industrial design.

Conclusion

The model proposed in the study has a flexible structure which enables the user to easily fine tune its properties according to each specific evaluation job at hand. This ease of use and flexibility makes the model very suitable for industrial design use.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

3B Modelleme Programlarının Endüstri Tasarımında Kullanım Açısından Değerlendirilmesi

Araştırma Makalesi / Research Article

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ÖZ

Bu makalede, akademik ve sanayide teorik ve uygulamalı birçok konuda değerlendirme amacı ile kullanılan, karşılaştırılan alternatifler arasında yapılan ikili karşılaştırmalara dayalı olarak çalışan analitik hiyerarşi yöntemi(AHY, AHP: Analytical Hierarchy Process) incelenmekte ve yöntemin kullanımı detaylı şekilde açıklanmaktadır. Yöntem, bilgisayar destekli tasarım(BDT) ve 3B modelleme programlarının endüstri tasarımı alanında kullanıma uygunluğunun değerlendirildiği bir alan çalışmasıyla uygulamalı olarak sunulmaktadır. Sonuç bölümünde, çalışmada elde edilen bulgular açıklanmakta, yorumlanmakta ve yöntemin endüstri tasarımı alanına getirebileceği katkılar tartışılmaktadır.

Anahtar Kelimeler: Analitik hiyerarşi yöntemi, endüstri tasarımı, ürün tasarımı, ikili karşılaştırma, yazılımların değerlendirilmesi.

Evaluation of 3D Modeling Programs For Industrial Design Use

ABSTRACT

In this article, Analytical Hierarchy Process (AHP) which had been used for evaluation purposes in numerous theoretic and practical fields in academic to industrial circles is investigated and the use of the method is explained in detail. The method is then demonstrated on a field study in which 3D modeling programs are evaluated fur suitability to the industrial design field. At the results section, the obtained findings are explained, interpreted and methods possible benefits to the industrial design field is argued.

Keywords: Analytical hierarchy process, industrial design, product design, pairwise comparison, software evaluation.

1. INTRODUCTION

Analytical Hierarchy Process (AHP) is a well proven evaluation tool which has been extensively used in almost every field of research that involves multi criteria decision making. Developed by Saaty, it has been used in various evaluation and decision making applications in later years [1].

Competition is pushing design and production firms to do process optimizations to obtain better results in their businesses. That optimization process is a tough one as it requires lots of planning for the problem to be correctly identified best possible solution for it to be found and realized efficiently. To integrate and ease up the work necessary for such optimizations, a number of computer aided design (CAD) systems have emerged in time [2].

A CAD system is a critical part of a computer aided manufacture(CAM) system and integrates different kinds of design and engineering tasks of the product development process in a virtual environment by means of computing technologies [3]. Therefore using a CAM system is advantageous for a firm as it maintains and enables the concurrent, fast and safe execution of tasks in product development like industrial design, engineering, reverse-engineering, logistics etc. The detailed modeling and analysis of a product for better understanding of its interior systems by using CAD programs during the design phase simplifies the management of the later production phases and product's life cycle [4].

Firms usually experience difficulties while they try to obtain the CAD-CAM software they need. Among these difficulties, probably the biggest one is the selection of the software package according to the company needs and expectations [5].

Software selection is a complex, multi-criteria decision making process that can be affected by many factors. As the costly failures experienced by firms due to the mistakes made in choosing and operating these kinds of systems are heard among other companies, making correct evaluations have started to get into more people's area of interest. Prices of these software systems are high and they generally require yet more expensive powerful computer systems to run. So it is an absolute necessity for the selected software-hardware system to provide a rise in design quality and flexibility in manufacture to cover and surpass all the expenses made for purchasing it [6].

For a firm specializing on industrial design, the selection of the CAD-CAM PC software package most suitable for their use is very important to be competitive in the global market. The product design process which contains many complex and multi-criteria decision making tasks can be

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simplified by using suitable tools that deal with and simplify these tasks individually [7]. Determining the most suitable 3D modeling program for industrial design can be thought of one of these individual tasks and to accomplish it, a versatile tool which is immune to external and internal influences can be helpful. This tool should be methodic, easy to use and suitable for use in a computer environment. AHP comes up as one of the available tools that can be used for this purpose, fulfilling the needs of the evaluation processes in industrial design. This article investigates AHP's suitability for use in industrial design and proposes a method for its application. First, the history of AHP is introduced briefly, then the steps of the method is explained in detail and the sample application is presented in which the proposed method is used for evaluating 3 candidate 3D modeling programs for the PC and selecting the most suitable one to be used in industrial design.

2. ANALYTICAL HIERARCHY PROCESS

AHP is first proposed by Myers and Alpert [8] and further developed for application in Wharton School of Business [1]. By means of the following studies in later years, AHP established a place for itself as a powerful and flexible tool in applications which require decision making and priority identification [9–12]. AHP is basically a measurement theory based on priority values obtained from pairwise comparisons between criteria and/or alternatives. It is very useful in solving decision making problems belonging to systems that incorporate complex relations with its subsystems and it works by analyzing and modeling these systems heuristically as a simplified hierarchical structure and studies them intuitively and logically [13]. By using this simplified structure, AHP prevents costly, distractive and delay imposing problems frequently encountered in large decision making processes like lack of focus, lack of involvement and planning mistakes [14].

AHP works mainly with weighted scale comparisons and its theoretical structure is based on four main axioms [15]:

Axiom 1 (Reciprocality): This is the basis for making pairwise comparisons. If the i^{th} criteria's importance value is x, then the importance value of the j^{th} criteria with respect to the i^{th} criteria shall be $\frac{1}{x}$.

Axiom 2 (Homogeneity): For the pairwise comparisons to be done correctly, any of the two criteria cannot be infinitely superior to the other.

Axiom 3 (Independency): Criteria and alternatives are independent from each other.

Axiom 4 (Hierarchy): The human mind can make comparisons among things which carry similarities with respect to a common property. If a decision problem or task is divided into sub units and presented within a hierarchical structure, every unit at the hierarchy tree has other items next to, above or below to be compared to. So rearranging the units to be compared within a hierarchical order provides extra reference values and simplifies the comparison process.

2.1 The Application of Analytical Hierarchy Process

AHP is realized briefly in three main phases: building a hierarchy diagram, derivation of the weighted importance values and verifying consistencies [1]. The first phase is to convert the decision making problem into a three leveled hierarchy diagram. Then, matrices are prepared for each hierarchy level and they are filled with data obtained from comparisons performed in interviews with participants of the experiment. Finally, at the priority analysis phase, every comparison matrix is solved by using the eigenvector method, which determines the relative importance of criteria and performance values of the alternatives [16].

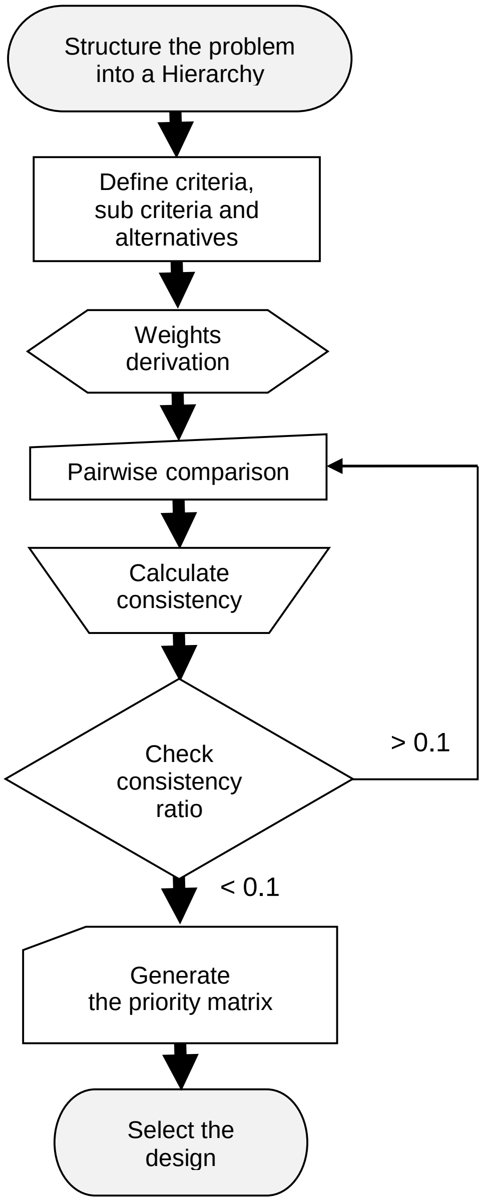


Figure 1. Flow chart of the Analytical Hierarchy Process

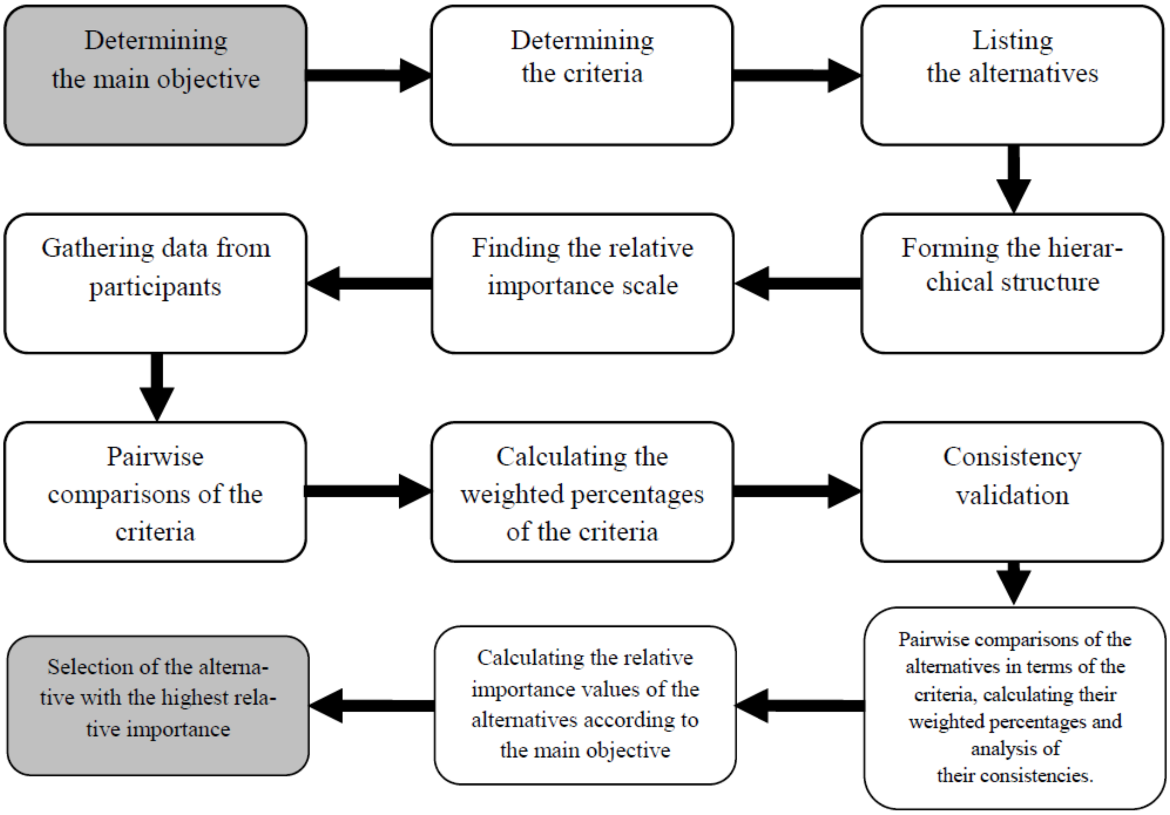


Figure 2. Analytic Hierarchy Process Steps

1) The first step is the determination of the main objective. It is the target which the decision makers would like to achieve by using AHP.

2) Criteria which will be used for evaluation are listed in this step. Care should be taken, as the success of the evaluations will depend on how correctly these criteria are determined. Experts of the field might be consulted and a needs list might help to decide which criteria should be considered in the process. The length of this list, as well as the amount of criteria can change according to the properties of the problem at hand [14].

3) The alternative to be further evaluated to reach the main objective is decided and prepared for evaluation.

4) A three leveled hierarchical structure is formed, with the main objective at the top, the criteria listed in second step occupying the middle and the alternatives in third step at the bottom level (Figure 3) and each group of items forming a hierarchically separate layer while the main objective occupies the whole top level on its own. Items which are at the same level are assumed to be independent according to Saaty's third axiom. The size of the hierarchical structure changes according to the complexity of the problem and the researchers' need for details to solve the problem [17]

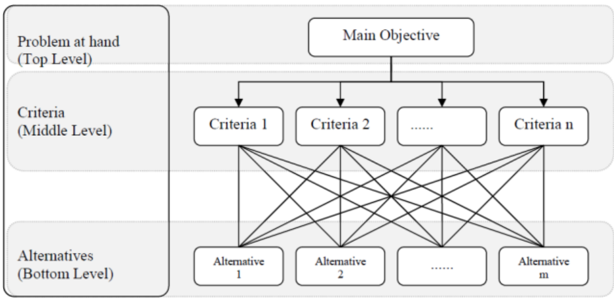


Figure 3. General Hierarchical Structure of AHP

5) For the pairwise comparison matrices to be formed, a relative priority scale consisting of numbers that show the importance values of the criteria is prepared. This scale enables all criteria to be separately evaluated for their effects upon the final decision. Saaty had developed the 1-9 scale which consists of 5 main and 4 intermediate values [1]. These values, their conceptual meanings and explanations can be seen in table 1.

Table 1. Relative importance scales used in AHP and their definitions

Relative Importance Value	Conceptual Meaning	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over the other
5	Essential or strong value	Experience strongly favors one requirement over the other
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over the other is on the highest possible order of affirmation
2,4,6,8	Intermediate values	These values should only be used when a compromise is needed.

6) During the application of the AHP, importance values of the criteria are rated by the participants in surveys or interviews according to the scale given in table 1. In this rating, every one of the criteria used in the process is compared one on one to every other criterion to obtain their relative importance values. As the consistency of the results and the final success of the evaluation will depend on the information gathered from the participants, they should be selected among people at least having sufficient knowledge or preferably experts of the field in which the main objective is about. They can be the members of the design team, designers from outside the firm or sometimes consumers who will eventually use the products. It is much easier to evaluate alternatives and make a final decision when this group has only one member; as the number of participants increase, it becomes more difficult to process all data manually and obtain a single judgment in the end. The average value of the data gathered from several people is calculated and used as a single entry during later calculations. While some researchers use the arithmetical mean average of data obtained from multiple people, Saaty states that this might create some consistency problems and believes that geometrical averaging would give better results [18].

7) At this step, pairwise comparison matrices are formed by using data obtained in step 6. In a decision process with n criteria, $\frac{n\,(n+1)}{2}$ comparisons are needed, producing nxn sized pairwise comparison matrices [19] When the importance value of the i^{th} criteria and the j^{th} criteria is shown with a_{ij}, generally the pairwise comparison matrix becomes like the one below [20].

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

The contents of the matrix A, which are the importance values of the pairwise comparisons, are positive numbers ($a_{ij}>0$, i,j=1,2,.....,n) while all diagonal values starting from a_{11} are 1. If the pairwise comparisons (matrix A) are fully consistent, the equation;

$$a_{ij}.a_{jk} = \left(\frac{w_i}{w_j}\right).\left(\frac{w_j}{w_k}\right) = \frac{w_i}{w_k} = a_{ik}$$

i,j,k=1,2,...,n should be true [1].

8) After the A matrix, which stores the importance values of the reciprocal comparisons is prepared, its value should be normalized. Various methods are used for this purpose. In the favorite method for many researchers, every column member is divided into the sum of the column where it is located. Where b_j shows the sum of the j^{th} column, the total value of the columns is calculated by using formula 1 below.

$$b_1 = \sum_{i=1}^{n} a_{i1} \tag{1}$$

Then, members of the reciprocal comparison matrix are divided into the total sum of the column in which they are located with the formula 2 below.

$$c_{ij} = \frac{a_{ij}}{b_i} \tag{2}$$

This gives us the C matrix (3) with nxn dimensions, comprised of c_{ij} members which are the normalized values of the comparisons.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ . & . & . & . \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \tag{3}$$

By using matrix C, relative importance or percentage weights of the criteria are calculated with the formula 4 below which gives the arithmetic mean of the line members of the C matrix.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{4}$$

This gives us the W matrix (5) which is comprised of the mean values of the lines of matrix C and stores the percentage weights of all the criteria.

$$W = \begin{vmatrix} w_1 = \dfrac{c_{11} + c_{12} + \ldots + c_{1n}}{n} \\ w_2 = \dfrac{c_{21} + c_{22} + \ldots + c_{2n}}{n} \\ \ldots \quad \ldots \quad \ldots \\ w_n = \dfrac{c_{n1} + c_{n2} + \ldots + c_{nn}}{n} \end{vmatrix} => \begin{bmatrix} w_1 \\ w_2 \\ . \\ w_n \end{bmatrix} \tag{5}$$

Performed normalization and other calculations related to the percentage weights of the criteria are summarized in table 2.

Table 2. Calculating the percentage weights of the criteria

	Criteria 1	Criteria 2	...	Criteria n	Criteria percentage weights
Criteria 1	$c_{11} = \frac{a_{11}}{b_1}$	$c_{12} = \frac{a_{12}}{b_2}$	...	$c_{1n} = \frac{a_{1n}}{b_n}$	$w_1 = \frac{c_{11} + c_{12} + \ldots}{n}$
Criteria 2	$c_{21} = \frac{a_{21}}{b_1}$	$c_{22} = \frac{a_{22}}{b_2}$	...	$c_{2n} = \frac{a_{2n}}{b_n}$	$w_2 = \frac{c_{21} + c_{22} + \ldots}{n}$
...	...	...	...	...	...
Criteria n	$c_{n1} = \frac{a_{n1}}{b_1}$	$c_{n2} = \frac{a_{n2}}{b_2}$	...	$c_{nn} = \frac{a_{nn}}{b_n}$	$w_n = \frac{c_{n1} + c_{n2} + \ldots}{n}$
Sum	$\sum_{i=1}^{n} c_{i1} = 1$	$\sum_{i=1}^{n} c_{i2} = 1$	...	$\sum_{i=1}^{n} c_{in} = 1$	$\sum_{i}^{n} w_i = 1$

9) Even though AHP has a very consistent system within its own, the success of its results still depends on the consistency of the pairwise comparison data gathered from the survey participants. So a consistency check function is also incorporated into AHP which is used to validate the individual comparisons by calculating their consistency ratio (CR). This function not only detects the erroneous evaluations that the participants perform during the surveys or interviews, it also shows exaggerated values in the data [14]. Calculating the CR depends on comparison between the number of criteria (n) and a coefficient called the base value (λ). For calculating λ, D column vector is calculated first by multiplying pairwise comparison matrix A with column vector matrix W which shows percentage weights of the criteria.

$$D = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ w_n \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ \cdot \\ d_n \end{bmatrix} \qquad (6)$$

By dividing each member of D matrix by the corresponding member of the W matrix, one e_i value is found for each evaluation criteria (7).

$$e_i = \frac{d_i}{w_i} \quad (i = 1,2,\ldots,n) \qquad (7)$$

By using formula 8, the average mean of the e_i values are calculated and used to calculate the base value (λ).

$$\lambda = \frac{\sum_{i=1}^{n} e_i}{n} \qquad (8)$$

Then the consistency index (CI) value is calculated by formula 9.

$$CI = \frac{\lambda - n}{n - 1} \qquad (9)$$

Finally as shown in equation 10, CR is obtained by dividing the calculated CI value by the RI value, which is the standard correction index value created by Saaty to calculate consistency ratio [1]. Number of criteria (n) versus corresponding necessary RI values are listed in table 3.

$$CR = \frac{CI}{RI} \qquad (10)$$

Acceptable upper limit for the consistency ratio is $\frac{1}{10}$.

Table 3. Number of criteria versus RI values.

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Having this number as the CR means that the inconsistency is 10% and the probability of these criteria comparisons being completely random is 0.1. So a CR value less than 0.1 means that the pairwise comparisons are consistent. If the CR value is more than 0.1, it is recommended to renew the comparisons corresponding to that CR value. This analysis and validation is repeated for all of the comparisons done in the project [14].

10) At this step, the alternatives are pairwise compared according to each criterion by using the importance values listed in table 1. Therefore for n criteria and m alternatives, nxm comparisons are made. Later as it was done for the criteria, normalized values for the alternatives are also calculated by dividing pairwise comparison column values (s_{ij}) by column sum (t_i)

Table 4. Comparison of alternatives according to criteria

	Pairwise comparisons of the alternatives according to criteria i				Normalized pairwise comparisons of the alternatives according to criteria i				Percentage weights of the alternatives according to criteria i
	Alt. 1	Alt. 2	...	Alt. m	Alt. 1	Alt. 2	...	Alt. m	v_{ij}
Alt. 1	s_{11}	s_{12}	...	s_{1m}	$u_{11} = \frac{s_{11}}{t_1}$	$u_{12} = \frac{s_{12}}{t_1}$	...	$u_{1m} = \frac{s_{1m}}{t_1}$	$v_{i1} = \frac{\sum_{j=1}^{m} u_{1j}}{m}$
Alt. 2	s_{21}	s_{22}	...	s_{2m}	$u_{21} = \frac{s_{21}}{t_1}$	$u_{22} = \frac{s_{22}}{t_1}$	...	$u_{2m} = \frac{s_{2m}}{t_1}$	$v_{i2} = \frac{\sum_{j=1}^{m} u_{2j}}{m}$
...	...	...	...	...	...	...	...	...	...
Alt. m	s_{m1}	s_{m2}	...	s_{mm}	$u_{m1} = \frac{s_{m1}}{t_1}$	$u_{m2} = \frac{s_{m2}}{t_1}$	...	$u_{mm} = \frac{s_{mm}}{t_1}$	$v_{im} = \frac{\sum_{j=1}^{m} u_{mj}}{m}$
Sum	$t_1 = \sum_{i=1}^{n} s_{i1}$	$t_2 = \sum_{i=1}^{n} s_{i2}$	...	$t_m = \sum_{i=1}^{n} s_{im}$	1	1	...	1	1

Percentage weights (v_{ij}) for every alternative and related criterion is calculated by taking mean averages of these values normalized for every criterion and every alternative. This shows the percentage weight of the j^{th} alternative according to the i^{th} criterion. Then as it was done for the criteria, consistency ratios are also calculated for the alternatives by taking these percentage weights into account. If the consistency ratio of the alternatives for the i^{th} (i=1,2,...,n) criterion is less than 0.1(CR<0.1), it can be said that participants have made a consistent evaluation at the pairwise comparison of the alternatives according to the i^{th} criterion. If CR>0.1, then pairwise comparisons for the alternatives according to the i^{th} criterion should be renewed to obtain more consistent values.

11) Before giving the final decision, the alternatives' relative importance values according to the main objective are calculated by using the weighted values obtained at the solution phase of the problem. For this, percentage weights for each alternative and each criterion (v_{ij} i=1,2,...,n; j=1,2,...,m) and percentage weights obtained by pairwise comparisons of the criteria (w_i i=1,2,...,n) are multiplied one to one. Then the results of these multiplications for each alternative are summed up to obtain the relative importance values (Z_j) of the alternatives.

12) At this final decision step, the relative importance value Z for each alternative is compared and the one with the highest value is selected as the strongest candidate to be used in reaching the main objective while fulfilling all requirements of the selected criteria.

2.2 Literature Review

After it was developed for application by Saaty, AHP had been used extensively in fields that mostly deal with qualitative data and need to have complex decision making and evaluation problems to be solved [9–12].

The tool's usage is in continuous rise today as it helps the analysis and solution of complex, multi criteria problems with its ease of use and flexibility. The method became even easier to use by means of several PC software packages that automated most of the paperwork and computing required for the process. There are even several online program packages nowadays which can be used free of charge. This enabled the method to be used in less professional environments and/or for more complex problems all of which helped to widen its spread [21,22].

To date, AHP had been used in econometrics, statistics, planning, energy management, resource allocation, health, dispute resolution, project selection, marketing, computing technologies, budget allocation, finance, education, sociology, architecture, and many other fields [17].

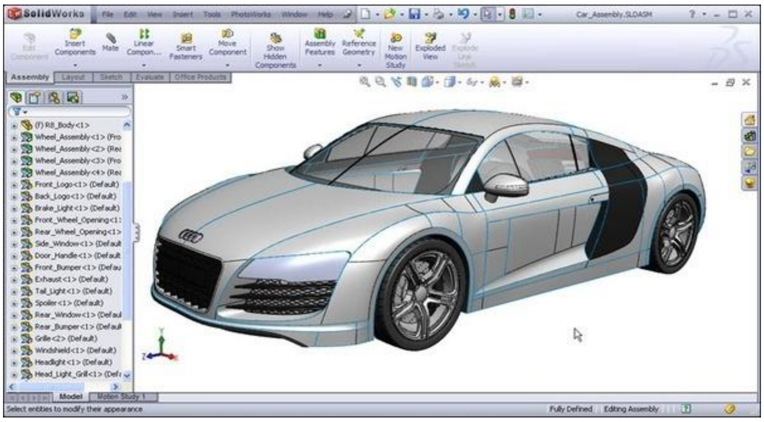
There are several studies in the literature about using AHP in product design but they have been usually concentrated on the engineering aspects of product development [23].

Some applications of AHP in product development are: planning a concurrent industrial product design process for a musical toy [24], the selection of the best energy type for a cooling product [25], evaluation of alternatives for a product design [26], selection of the best supplier firms in the design phase of a communications system [27].

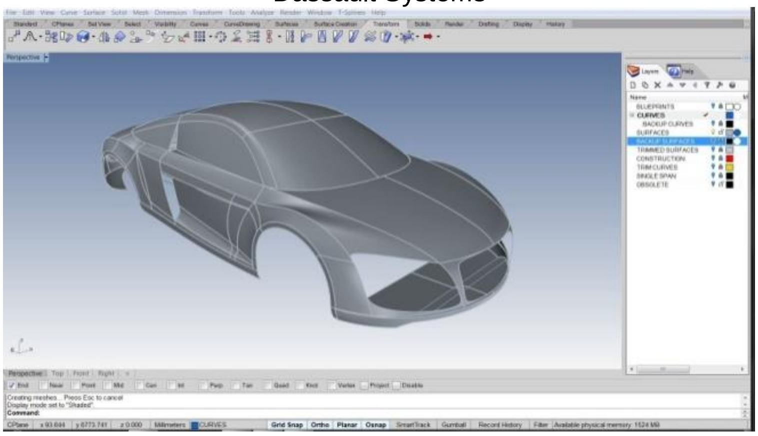
There are also a number of preliminary studies in product design and development for the application of AHP in CAD software selection [28,29] or simulating the development of CAD systems [30].

3. USING AHP FOR EVALUATION OF SOFTWARE PACKAGES FOR INDUSTRIAL DESIGN

This research is done in a university design research center with the participation of an industrial designer who is an expert in multidisciplinary studies with experience on all three software packages. Three PC program alternatives (Figure 4) taken among various programs used for industrial design were used in the process. These program packages are accepted as the input for the research and used in the evaluation-selection experiment. This experiment is performed to demonstrate the use of AHP at the decision process in which one of the candidate PC programs is selected as the most suitable software package for general industrial design use.



PP-1: Solidworks
Dassault Systems



PP-2: Rhinoceros 3D
Robert Mc Neel and Associates

Figure 4. PC Program Packages (PP) one of which will be selected as the most suitable one for general industrial design use.

This article aims primarily to introduce AHP to industrial design and to demonstrate the usage of it on a simple application with no intention to actually evaluate all candidate PC programs and determine which one is the most suitable for design purposes. There are a great number of 3d modeling program packages which are used in industrial product design. Therefore only three of the programs on the market are taken into the context of the selection job to obtain a process which is easy to demonstrate.

For a PC program for use in industrial design to be chosen, the flowchart and the steps of AHP shown in figure 1-2 are executed. The first step is the definition of the main objective and it is determined as "selecting the best 3D modeling program" motion simulation, structural validation, assembly animation, photo-realistic screen images, rendering, walk-through animation, reliability, documentation, technical support. After the determination of the criteria and the sub criteria (Figure 5), alternatives are required to be listed. The 3 PC program packages are named as PP-1, PP-2 and PP-3as the alternatives in this study (Figure 4).

Most important phase of the AHP process is forming the hierarchical structure and it should be done very carefully as any mistake might negatively affect the later stages of the process. At the complete hierarchical structure in figure 6, the top level shows the main purpose of the study, medium level lists the criteria-sub criteria and the bottom level lists the alternatives to be evaluated. This

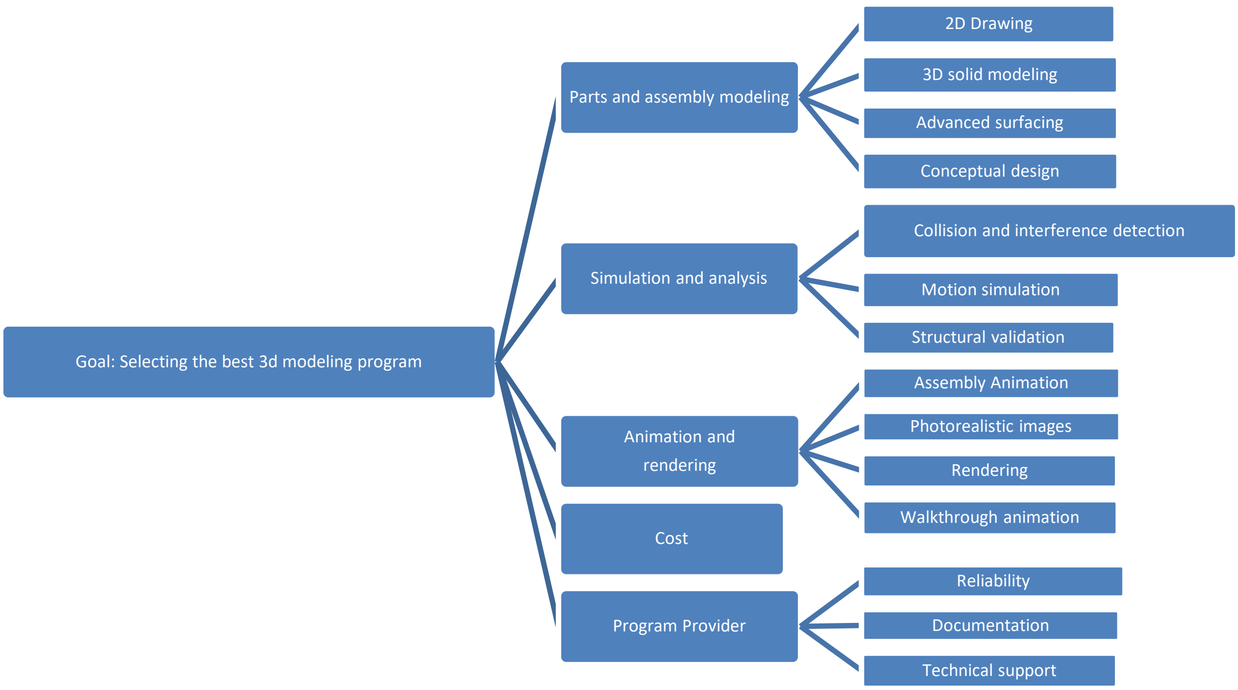


Figure 5. Main goal, criteria and subcriteria in a hierarchy tree

After defining the main objective and carefully studying other academic studies related to software evaluation, [2,5,34,6,11,11,19,28,31–33] the criteria which will be taken into account during selection are defined as: Parts and assembly modeling capability, simulation and analysis capability, animation and rendering capability, cost, program provider's capabilities. Then by utilizing the combined experience of the research participants, these main criteria are divided into 14 sub criteria as; 2D drawing, 3D solid modeling, advanced surfacing, conceptual design, collision and interference detection, structure is also used for maintaining the order of its contents while they are used in the process. First the criteria and sub criteria are used as the input for a PC program specifically designed to be used in the application of AHP.

Then empty pairwise comparison matrices generated by the program are filled with data gathered from the participants during the interviews. The computer program then executed the sequence of AHP steps shown in figure 1 which have also been explained in detail in the previous section.

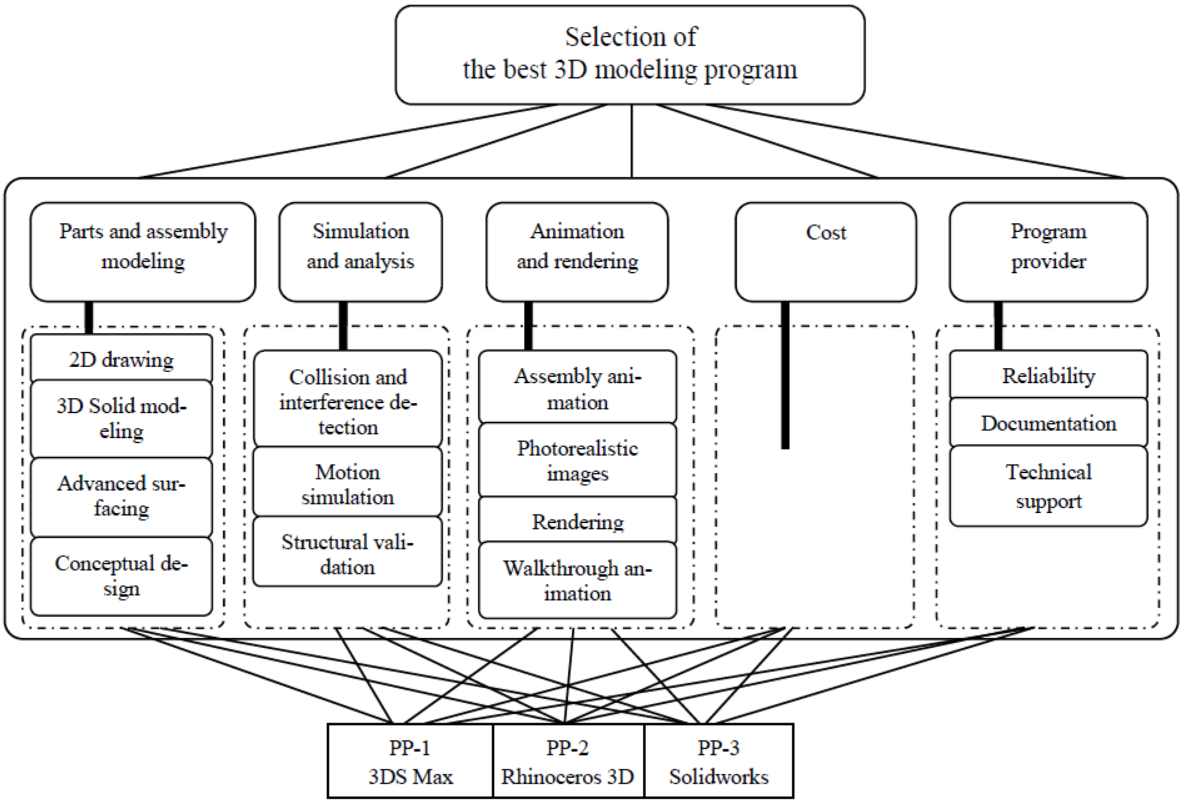


Figure 6. Complete AHP hierarchical model which will be used in the study

3.1 Statistical Findings

Findings obtained from our study and their interpretations are presented at this section. All criteria, sub criteria and alternatives were subjected to comparisons two at a time, starting with the main criteria listed at table 5. After pairwise comparison matrices generated by the PC program are filled with data obtained from the interview, the program is executed and calculated results are summarized below

According to the findings presented in table 5, the most important criteria for the 3D modeling program is turned out to be parts and assembly modeling capability and it is followed by simulation and analysis capability, animation and rendering capability, cost and program provider's capabilities. As the inconsistency ratio is 0.09<0.1, the performed evaluation is deemed to be successful. A similar result can be seen in general analysis of the model which is shown in table 6. The highest importance value of 60.1% belongs to the criteria of parts and assembly modeling.

Table 5. Results for the pairwise comparisons of the main criteria

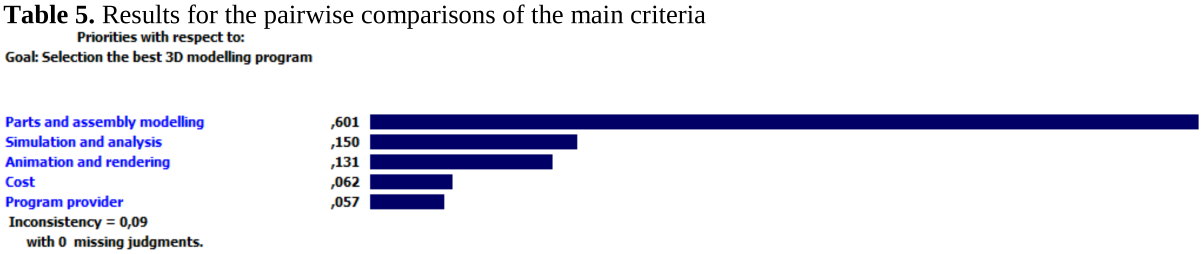


Table 6. General Analysis of the model

- Goal: Selection the best 3D modeling program
  - Parts and assembly modeling (L: ,601)
    - 2D drawing (L: ,037)
    - 3D SolidModeling (L: ,523)
    - Advanced surfacing (L: ,262)
    - Conseptual design (L: ,178)
  - Simulation and analysis (L: ,150)
    - Collision and interference (L: ,094)
    - Motion simulation (L: ,627)
    - Structural validation (L: ,280)
  - Animation and rendering (L: ,131)
    - Assembly animation (L: ,076)
    - Photorealistic images (L: ,611)
    - Rendering (L: ,255)
    - Walk through animation (L: ,059)
  - Cost (L: ,062)
  - Program provider (L: ,057)
    - Reliability (L: ,078)
    - Documentation (L: ,287)
    - Technical support (L: ,635)

The values for the sub criteria are also seen in table 6, together with the values for criteria. When these weighted results are examined, it is seen that "3D solid modeling" (52%) which is a sub criteria of parts and assembly modeling, "motion simulation"(62.7%) which is a sub criteria of simulation and analysis, "photo realistic images"(61.1%) which is a sub criteria of animation-rendering and "technical support"(63.5%) which is a sub criteria of program provider had the highest values and are therefore found to be the most important criteria in the evaluation. The consistency ratio is below 0.1, validating these values.

Table 7. Weighted results for the program package alternatives.

	Program Package Alternatives	Weighted Results
PP-1	3DS MAX	0.193
PP-2	Rhinoceros 3D	0.262
PP-3	Solidworks	0.545

Finally the resulting weighted importance values for the 3 program package alternatives are listed in table 7. When these values are examined, it is seen that 3D modeling program no 3 (PP-3: Solidworks) has the highest weighted importance value (54.5%)

3.2 Sensitivity Analysis and Interpretation

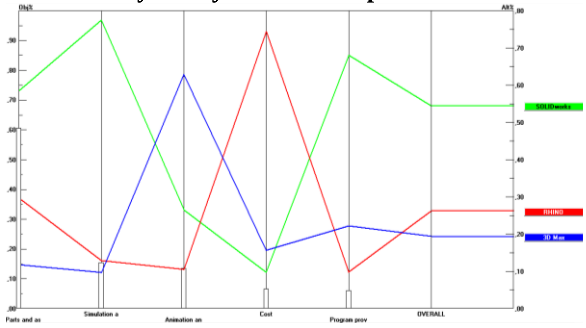


Figure 7. Sensitivity Percentages of Alternatives According to Criteria

According to the results presented in figure 7, the success levels for parts and assembly criteria of PP-3(Solidworks) is found to be 73% while PP-2(Rhinoceros) is 36% and PP-1(3DS) is 15% successful, for the simulation and analysis criteria, PP-1 is 15%, PP-2 is 17%, PP-3 is 97% successful, for animation and rendering criteria, PP-1 is 15%, PP-2 is 36%, PP-3 is 34% successful, for cost criteria, PP-1 is 22%, PP-2 is 36% and PP-3 is 16% successful, for program provider's capabilities criteria, PP-1 is 25%, PP-2 is 15% and PP-3 are 85% successful.

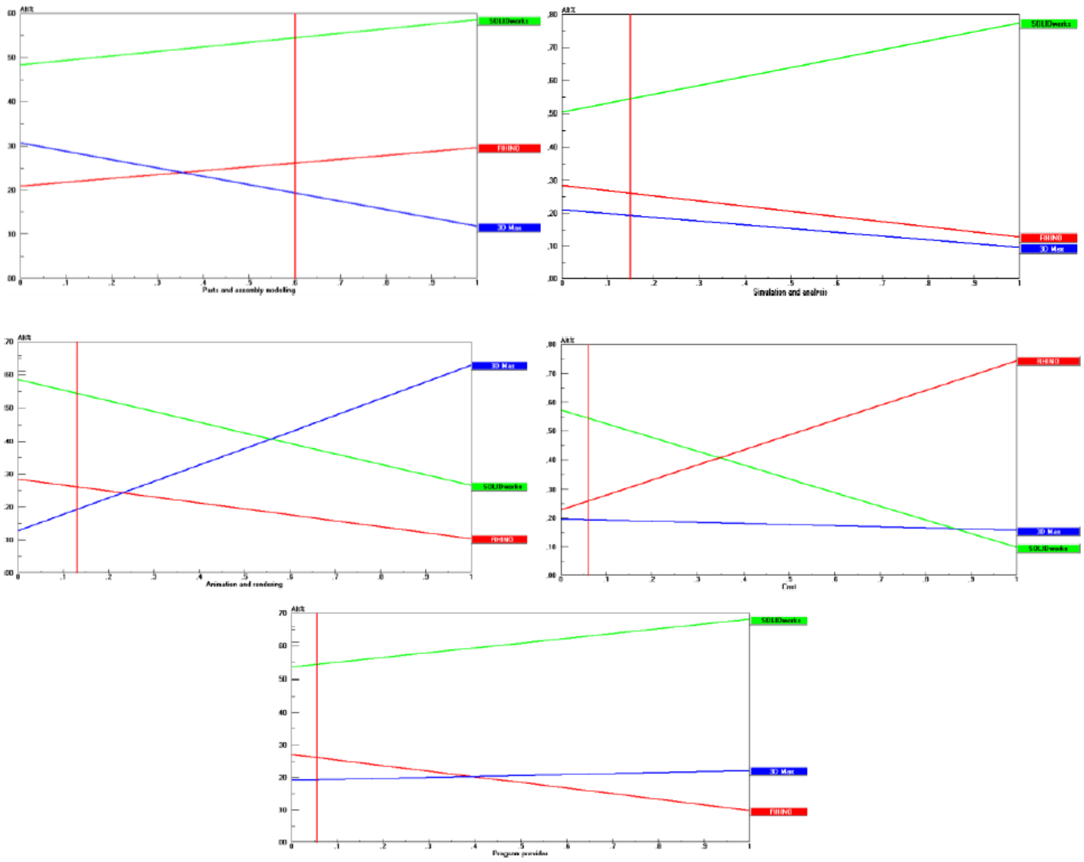


Figure 8. Gradient Sensitivity

Alternatives' criteria based relative relations to each other are shown in the gradient charts which are usually generated for the main criteria. The charts above (figure 8) display the changes of the weighted importance of the alternatives according to changes at the weighted importance of the performance criteria the highest, PP-3 and the lowest, PP-1, in their responses to the changes in criteria importance. Figure 10 below shows the comparison for PP-1 and PP-2. Other alternatives can also be compared in a similar if required.

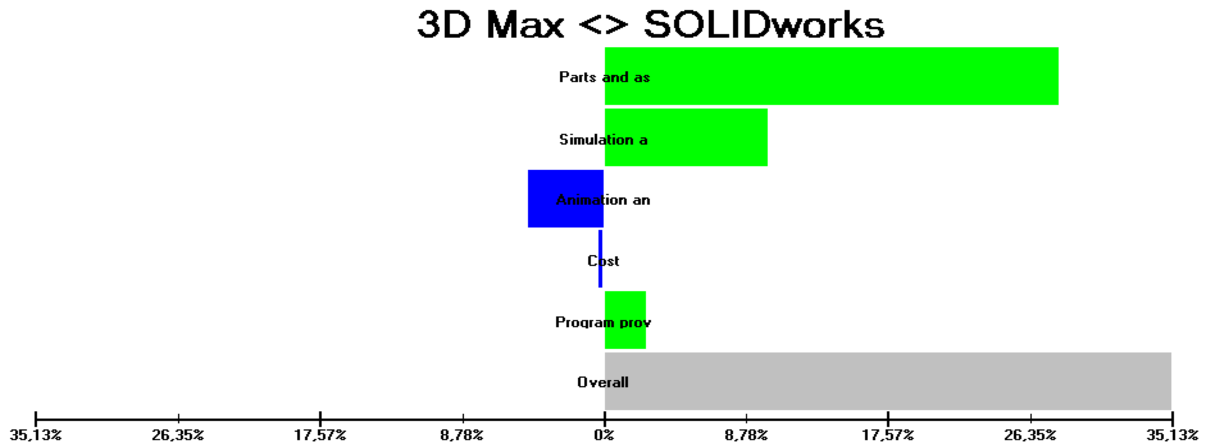


Figure 9. Head-to-Head Sensitivities for 3DS Max and Solidworks

The head-to-head sensitivity graphic in figure 9 shows the comparison of two selected alternatives,

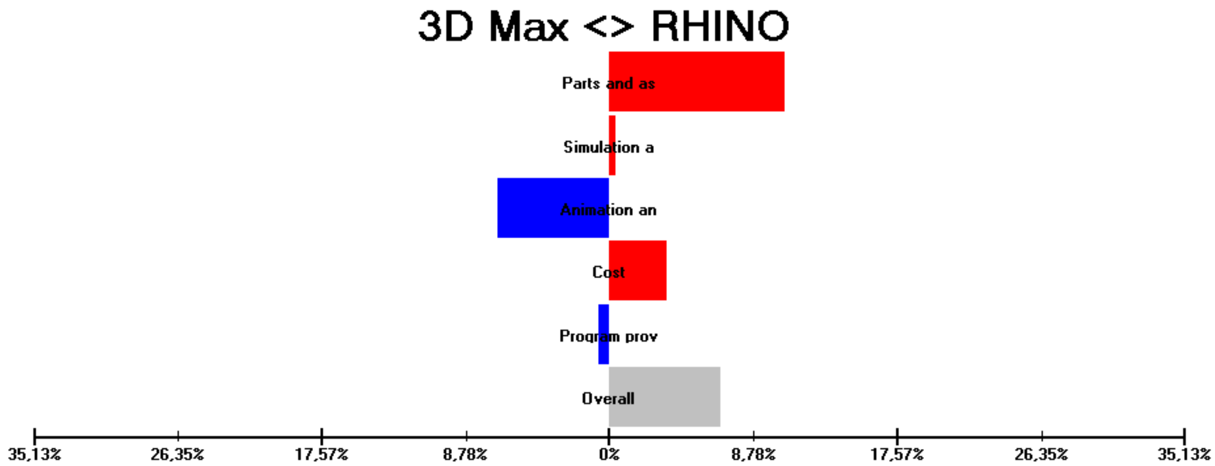


Figure 10. Head-to-Head Sensitivities for 3DS Max and Rhinoceros 3D

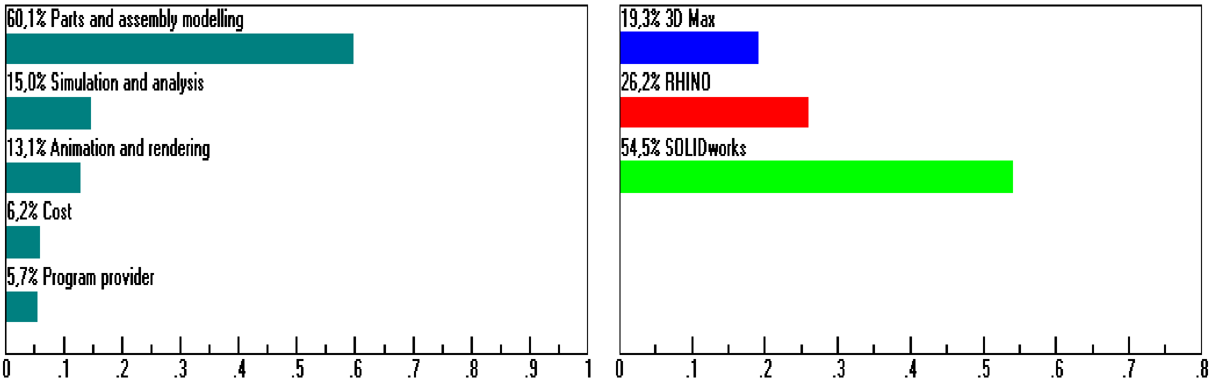


Figure 11. Dynamic Sensitivity

According to the criteria based dynamic sensitivity shown in figure 11, parts and assembly modeling is the most important(60.1%) main criteria while program provider's capabilities is found to be the least important(5.7%). For the alternatives, PP-3(Solidworks) has the highest value (54.5%) and PP-1(3DS Max) has the lowest (19.3%). Therefore after considering all criteria and sub criteria, PP-3 comes up as the best 3D modeling program for use in industrial design processes.

3.3 Verification of the Findings

As the last step of the research, a validation interview was conducted to evaluate the obtained results with the participation of an industrial design instructor who uses and/or gives lectures on all three program packages. General questions were prepared about the overall structure, specifications and functions of the programs to aid the validation process and were asked to the participant during the interview which was performed like an informal talk. Similar to the validation procedure performed by Harputlugil [35], the questions were ranked by using 1-10 scale (Table 8). During the interview, the questions and rankings were also assessed and argued in detail with the participant.

Table 8. Interview questions and obtained rankings

	Questions	Rankings
1	Please rank PP-1 in terms of interface and overall use	7
2	Please rank PP-2 in terms of interface and overall use	6
3	Please rank PP-3 in terms of interface and overall use	9
4	Please rank PP-1 for its functions' suitability to industrial design	6
5	Please rank PP-1 for its functions' suitability to industrial design	5
6	Please rank PP-1 for its functions' suitability to industrial design	9
7	Please rank the reliability of PP-1	8
8	Please rank the reliability of PP-2	5
9	Please rank the reliability of PP-3	9
8	Please rank your recommendation of PP-1 for the industrial design process	5
9	Please rank your recommendation of PP-2 for the industrial design process	4
10	Please rank your recommendation of PP-3 for the industrial design process	8

According to the validation survey results, PP-3(Solidworks) with its sophisticated interface design, feature history, parametric design, assembly creation and many other capabilities has a higher capacity to fulfill the requirements of a professional industrial designer than PP-1 (3DS) and PP-2 (Rhinoceros). It was argued in the interview that PP-3 is more capable in terms of its functions and also found to be more reliable in operation. While PP-2 received a higher rank for its low cost, PP-1 has received a slightly higher rank for being the oldest and the most mature software among the three. And while PP-1 and PP-2 with their balancing advantages and disadvantages showed similar overall performances in this validation and receiving close ranks in overall, PP-3 received a considerably higher rank for being more suitable for use in the industrial design process therefore verifying the findings obtained in the article by using the AHP method.

4. RESULTS

In this study, the use of AHP as a multiple criteria evaluation and decision making tool is investigated for use in general industrial design process and a model is proposed for its application. The tool and the model are demonstrated with a sample industrial design study in which several PC programs for 3d modeling are evaluated according to their suitability for industrial design and then the best one is selected according to the obtained findings.

During the process of evaluations and selections in industrial design, many criteria are required to be taken into consideration to correctly determine which of the available alternatives to be chosen. In the specific application model used in this study, a selection of five criteria and eleven sub criteria are used. The quantitative importance for each of these criteria is calculated. Then sensitivity analyses for the importance weights of main criteria are performed for investigating how much and towards which direction the results are affected by the changes in the criteria. With the solution of the model, main criteria are ordered from high to low according to weighted importance values, displaying their real world importance according to the experts participated in the study. After the alternatives are processed by the computer program according to the criteria, their weighted importance final values are obtained in a decreasing order. This sequence of values produced by the program enabled the decision makers to clearly and easily see which of the alternative pc programs has a better suitability to industrial design purposes.

The AHP model used in our study has a flexible structure which enables the user to add or change criteria, sub criteria and/or alternatives easily. This flexibility of the model and the speed of the computer program give the user the chance to see the changes in any of the output values simultaneously when any one of the inputs changes. This enables the necessary changes and/or corrections to the process to be performed quickly.

With its consistency checking features, AHP enables decisions to be made according to many qualitative and quantitative criteria by using data which might even be to a degree unreliable and/or personal. As AHP includes the tools for working with both objective and subjective inputs along with the tools to validate the processes, it ensures that the results of the selections are as consistent and unbiased as possible. Therefore it is a very suitable methodology for use in various tasks of the industrial design process that require difficult multi-criteria decisions to be made by using data gathered from people that mostly reflect their personal thoughts. The methodic nature of AHP makes it a useful, effective and valuable tool for industrial designers by simplifying the design tasks with the use of automation, enabling more successful design projects to be completed in shorter time.

Using computer programs in the application of AHP simplifies the use of the method, ensures the process steps are executed in the right order and prevents mistakes which are likely to happen when manually entering data during interviews and doing matrix calculations in later stages. It also enables the method to be used on more complex problems which would be very hard to implement manually.

Consequently, as a method well known for its simplicity, flexibility, ease of use and ease of interpretation in the analysis of complex multi-criteria decision problems, AHP is suitable for use at the industrial design process with its capability of being applied to various tasks of the process easily. The use of AHP is expected to simplify and shorten the design process, enabling products with higher design quality to be created and presented to consumers in the future.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

REFERENCES

[1] T.L. Saaty, "The Analytic Hierarchy Process", ***McGraw-Hill,*** New York, (1980).

[2] Z. Ayag, "A combined fuzzy AHP-simulation approach to CAD software selection", ***International Journal of General System,.*** 39(7): 731–756, (2010).

[3] K.L. Narayan, K.M. Rao, M. Sarcar, "Computer Aided Design and Manufacturing", ***Prentice Hall of India***, ISBN-978-81-203-3342-0, New Delhi, (2008).

[4] M. Evans, "The Potential of Computer Aided Industrial Design to Act as a Catalyst for Greater Professional Collaboration", ***ASIS Midyear Proceedings in Collaboration Across Boundaries: Theories, Strategies, and Technology***, Orlando, Florida, (1998).

[5] J.A.W. Mulebeke, L. Zheng, "Analytical network process for software selection in product development: A case study", ***Journal of Engineering and Technology Management,*** 23(4): 337–352, (2006).

[6] A.S. Jadhav, R.M. Sonar, "Evaluating and selecting software packages: A review", ***Information and Software Technology,*** 51(3): 555–563, (2009).

[7] L. Xu, Z. Li, S. Li, F. Tang, "A decision support system for product design in concurrent engineering", ***Decision Support Systems,*** 42(4): 2029–2042, (2007).

[8] J.H. Myers, M.I. Alpert, "Determinant buying attributes: Meaning and Measurement", ***Journal of Marketing,*** 32: 13–20, (1968).

[9] O.S. Vaidya, S. Kumar, "Analytic hierarchy process: An overview of applications", ***European Journal of Operational Research,*** 169(1): 1–29, (2006).

[10] S.C. Cheng, T.C. Chou, C.L. Yang, H.Y. Chang, "A semantic learning for content-based image retrieval using analytical hierarchy process", ***Expert Systems with Applications***, 28(3): 495–505, (2005).

[11] V.S. Lai, R.P. Trueblood, B.K. Wong, "Software selection: A case study of the application of the analytical hierarchical process to the selection of a multimedia authoring system", ***Information & Management,*** 36(4): 221–232, (1999).

[12] H. Min, "Location analysis of international consolidation terminals using the analytic hierarchy process", ***Journal of Business Logistics,*** 15(2): 25, (1994).

[13] H.Ü. Özden, "Analitik Hiyerarşi Yönetimi İle İlkokul Seçimi", ***Marmara Üniversitesi İkdisadi ve İdari Birimler Dergisi,*** 24(1): 299–320, (2008).

[14] A. Koçak, "Yazılım Seçiminde Analitik Hiyerarşi Yöntemi Yaklaşımı ve Bir Uygulama", ***Ege Academic Review,*** 3(1): 67–77, (2003).

[15] T.L. Saaty, "Decision making with the analytic hierarchy process", ***International Journal of Services Sciences,*** 1(1): 83, (2008).

[16] S.C. Cheng, M.Y. Chen, H.Y. Chang, T.C. Chou, "Semantic-based facial expression recognition using analytical hierarchy process", ***Expert Systems with Applications,*** 33(1): 86–95, (2007).

[17] F. Zahedi, "The Analytic Hierarchy Process: A Survey of the Method and Its Applications", ***Interfaces,*** 16(4): 96–108, (1986).

[18] T.L. Saaty, "The analytic hierarchy process: what it is and how it is used", ***Mathematical Modeling,*** 9(3): 161–176, (1987).

[19] A. Kuruüzüm, N. Atsan, "Analitik Hiyerarşi Yönteminin İşletmecilik Alanındaki Uygulamaları", ***Akdeniz İ.İ.B.F Dergisi,*** (1): 83–105, (2001).

[20] A. Oğuzlar, "Analitik Hiyerarşi Süreci ile Müşteri Şikayetlerinin Analizi", ***Akdeniz İ.İ.B.F Dergisi,*** (14): 122–134, (2007).

[21] E. Forman, S. Gass, "The Analytic Hierarchy Process – An Exposition", ***Operations Research,*** 49(4): 469–486, (2001).

[22] S. Felek, Y. Yuluğkural, Z. Aladağ, "Comparing

AHP and ANP Results to Estimate Market Share in Mobile Communication Sector", ***Endüstri Mühendisliği Dergisi,*** 18(1): 6–22, (2007).

[23] A. Hambali, S.M. Sapuan, I. Napsiah, Y. Nukman, "Use of analytical hierarchy process (AHP) for selecting the best design concept", ***Jurnal Teknologi***, 49(A): 1–18, (2008).

[24] S. Hsiao, "Concurrent design method for developing a new product", ***International Journal of Industrial Ergonomics,*** 29(1): 41–55, (2002) .

[25] F. Dweiri, F.M. Al-Oqla, "Material selection using analytical hierarchy process", ***International Journal of Computer Applications in Technology,*** 26(4): 182–189, (2006).

[26] R.D. Henderson, S.P. Dutta, "Use of the analytic hierarchy process in ergonomic analysis", ***International Journal of Industrial Ergonomics,*** 9(4): 275–282, (1992).

[27] M.C.Y. Tam, V.M.R. Tummala, "An application of the AHP in vendor selection of a telecommunications system", ***The International Journal of Management Science,*** 29(2003): 171–182, (2001).

[28] S. Dönmez, "Computer Aided Industrial Design Software Selection in Industrial Product Design Education at Turkey Using Expert Choice Program", ***Procedia - Social and Behavioral Sciences,*** 106: 682–689, (2013).

[29] Z. Ayağ, "Cad software evaluation for product design to exchange data in a supply chain network", ***International Journal of Supply Chain Management,*** 4(1): 30–38, (2015).

[30] Z. Ayag, "An analytic-hierarchy-process based simulation model for implementation and analysis of computer-aided systems", ***International Journal of Production Research,*** 40:(13): 3053–3073, (2002).

[31] T. Tomiyama, Y. Umeda, H. Yoshikawa, "A CAD for Functional Design", ***CIRP Annals - Manufacturing Technology,*** 42 (1): 143–146, (1993).

[32] J. Karlsson, C. Wohlin, B. Regnell, "An evaluation of methods for prioritizing software requirements", ***Information and Software Technology,*** 39(14–15): 939–947, (1998).

[33] D.R. Jeske, X. Zhang, "Some successful approaches to software reliability modeling in industry", ***Journal of Systems and Software,*** 74(1 SPEC. ISS.): 85–99, (2005).

[34] S. Ereeş, E. Kuruoğlu, N. Moralı, "An Application of Analytical Hierarchy Process for Simulation Software Selection in Education Area", ***Frontiers in Science,*** 3(2): 66–70, (2013).

[35] T. Harputlugil, A.T. Gültekin, M. Prins, Y.I. Topçu, "Architectural design quality assessment based on analytic hierarchy process: A case study", ***Metu Journal of the Faculty of Architecture,*** 31(2): 139–161, (2014)