Application of a simplified value analysis methodology (VAM-2P) and CAD/CAE tools to Agro-industrial product redesign: Harvesting trolley case study

Juan José Robles López [1], Óscar González-Yebra [1,2], Fernando J. Aguilar [1], and Manuel A. Aguilar [1]

[1] University of Almería, Research Center CIAIMBITAL, Almería 04120, Spain
maguilar@ual.es
[2] International University of La Rioja, Higher School of Engineering and Technology, Spain

Abstract. The agri-food sector is an area where the design component can be considered to play a minor role as a non-technological driver of innovation. Unlike sectors like graphic design and communication, intellectual property protection is limited in industrial design, hindering innovation. To address this gap, the presented proposal advocates for an educational initiative to cultivate interest in industrial design among engineering students, following the UNE 144001 IN standard. The proposed methodology, called Value Analysis Methodology in 2 phases (VAM-2P), simplifies value analysis to prompt quick idea generation without focusing on economic aspect. On a first step, the students identify user needs in relation with the object to be redesigned. After that, CAD/CAE tools are used to generate 3D models and evaluate solutions against technical constraints. A case study on eco-design for a harvesting trolley illustrates this approach, emphasizing the use of SolidWorks 3D CAD® software to assess environmental impacts. This initiative aligns with Sustainable Development Goal 4 (SDG 4) and Target 4.4 of 2030 Agenda for Sustainable Development, which aims to increase the acquisition of relevant skills needed to promote entrepreneurship among young people and adults.

Keywords: Design-driven innovation, Higher education, Value analysis, CAD/CAE tools, Sustainability

1 Introduction

In spite of the fact that Spain has become the leading producer of organic agriculture in the European, the agri-food sector is an area where the presence of the "design" component as a strategic line and non-technological innovation factor, is practically non-existent [1]. A survey carried out in fruit and vegetables companies from southeast Spain found that around 70% of the participants had legally protected/registered a trademark related with graphic/communication, while in the industrial domain of the sector, the number of companies that had protected a trademark was lower (20%), with only one company protecting an industrial design [2]. In this scenario, as Martin-Doñate et al. [3] pointed out in a series of workshops on industrial design as a strategic tool for self-employment, it is the engineer who must have the ability to conceptualise (ideas, solutions, processes...) and bring the concept into reality.

The main goal of this work is to propose a teaching initiative that will stimulate and encourage interest in industrial design, creative empowerment, and design-led innovation among students of Industrial and Agricultural Engineering. An abbreviated Value Analysis Methodology is proposed, where (1) the potential client is interviewed to identify the needs of the product to be redesigned, and (2) the functions to be fulfilled by the new design are determined. The case study implements the VAM-2P which adds a third step: the inclusion of environmental vector in the redesign process.

2 Adaptation of the Value Analysis Methodology in 2 phases (VAM-2P)

For the development of the proposal, the UNE 144001 IN standard "Guide for the design and development of value analysis projects" [4] was used as a reference. In this sense, it should be noted that the Value Analysis Methodology (VAM) is applied by carrying out six work phases: i) Preparation and Orientation, ii) Information, iii) Functional and Costs Analysis, iv) Innovation and Creativity, v) Evaluation, vi) Implementation and Monitoring. However, the aim is to propose a reduced version that is easy to apply, obtaining a quick conceptualisation of alternatives, without taking into account the economic variable. With this adaptation, the goal is to have a tool that allows students of Graphic Expression, Computer Aided Design, Projects and Technical Office to be introduced to the philosophy of value analysis and promote innovation. To this end, a new VAM version is proposed by abbreviating the process into two phases (VAM-2P). Specifically, in the first phase, the needs of the users are identified in relation to the object to be redesigned, based on the inputs obtained from a survey of potential consumers in three dimensions (satisfaction, conformity, and interest/proposals). In a second phase, the functions are identified and possible alternatives to the initial product are designed, based on the functions that have obtained the highest percentages of evaluation (as design constraints) [5]. Finally, considering the results of a recent systematic review on the circular economy (CE) and industrial products, which suggests that CE practices (e.g., eco-innovation and eco-design) should be included in the subjects of the degrees taught by engineering schools [6], it is proposed to introduce the environmental vector in the redesign process as the last phase of the new methodological proposal. A summary of the described workflow is presented in Figure 1.

In order to do so and following a similar approach to that developed by González-Yebra et al. [7], we decided to include "CAD-CAE tools" and "eco-design strategies" in the same workflow, proposing the substitution of one or more materials by another or others with a lower environmental impact, aiming to progress in the improvement of the circularity of the design/product. Although the second phase is conceptual in nature, it is proposed the use of CAD/CAE tools, specifically the SolidWorks 3D CAD® (SW) software, since it offers a range of possibilities for generating 3D solids that can be quickly modified and have a realistic appearance. For the analysis of the final redesign's life cycle, the "Sustainability" module of the SW is used. Sustainability is based on the

CML methodology developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands. It is used to calculate potential impact factors being currently considered as one of the most comprehensive ones [8].

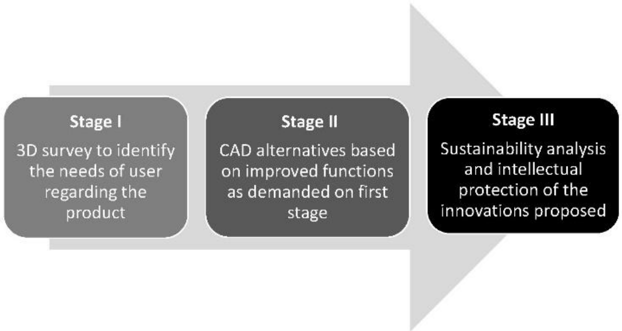

Fig. 1. Basic workflow of the proposal VAM-2P.

3 Study case: harvesting trolley redesign

The approach carried out in this work could be applied to the design of any industrial product, although this initiative is part of a line of research dealing with the development of design in the agri-food sector [1,2], which is why the redesign of a harvesting trolley is proposed as a case study (several 3D modelled examples can be seen in Fig. 2). As its use is still widespread, it was selected as an agro-industrial product of potential interest.

3.1 Data collection and needs assessment (first phase VAM-2P)

As a starting point for the first phase, the research group carried out a functional analysis to inventory the needs to be met by the trolley (e.g., ergonomics, ease of maintenance, quality materials, among other). Subsequently, the data collection instrument was designed, proposing a survey in three dimensions (satisfaction, conformity, and interest/proposals), including, as far as possible, five questions for each of the dimensions. The complete list of product characteristics evaluated on the survey can be found in Table 1.

To carry out said first phase of the field study, the Microsoft Forms platform was used, since it is freely accessible and offers graphical and statistical support, a user-friendly graphical environment (including responsive design, adapted to mobile devices) and the possibility of exporting the data using an Excel spreadsheet. For the distribution of the consultation to potential clients, a leaflet was designed with a short informative slogan and two links to the study, a QR code and web link: https://n9.cl/dguh9. The final consultation panel consisted of 30 farmers (83% male and 17% female), with the range 25-34 years being the most representative.

Table 1. Recapitulation of the product characteristics to be evaluated in each dimension (satisfaction, conformity, interest).

Product characteristic		
Level of satisfaction (1 - very unsatisfied to 5- very satisfied)	Level of conformity (1 - totally disagree to 5- totally agree)	Level of interest (1 - not interesting to 5- very interesting)
Comfort	Adequacy of the wheels to the terrain	Cheaper price
Capabilities	Safety hazard due to entrapment	Add-ons
Price	Safety risks due to clashes	Modular construction
Maintenance	Stability of the load	Easy driving
Safety	Right dimensions for the greenhouse	Bigger capacity
Aesthetics	Easiness to move the load	Lighter
Reliability	Bears sufficient volume	Direction

To determine the percentual relevance of the different characteristics that the consumers are asked about in the questionnaire, an equation was used (Eq. 1). This equation is a proposal developed purposely for the methodological version of the VAM developed in this paper. The value obtained represents the room for improvement of the feature. If 30 respondents are sampled, and each respondent rates the characteristic as ideal, then the characteristic will receive a score of 30 points, which represents 100%.

$$Valuation(\%) = \frac{(1 \cdot \mathrm{G5}) + (0.5 \cdot \mathrm{G4}) + (0 \cdot \mathrm{G3}) + (-0.5 \cdot \mathrm{G2}) + (-1 \cdot \mathrm{G1})}{30} \cdot 100 \qquad (1)$$

In Equation 1, G5 are the replies showing current happiness with the existing product, decreasing through G4, G3 and G2 till G1, which would represent the biggest gap between the covered necessities of the client and the existing characteristics.

Once the valuation ratings have been obtained, the next step is to compare the data with the needs initially listed. Based on the evaluation data obtained, which measure the consumer's relationship with the product, the aim is to obtain a numerical value that relates these characteristics to the needs. To do this, the following formulas are used:

$$N - C_1 = (1 - Valuation) \cdot \frac{Relevance}{10} \qquad (2)$$

$$N - C_2 = (Valuation) \cdot \frac{Relevance}{10} \qquad (3)$$

Where, N-C is the need-characteristic index, a numerical value that grades the importance of the characteristic in satisfying a given need, which in turn is self-regulated by the importance of the characteristic to the customer. For this reason, a distinction is made between the formulas to determine which of them have a positive connotation when talking about improvements (interest) and which should contribute less (conformity, satisfaction with the current situation).

- Valuation is the relevance, this time expressed as a percentage of one, that the customer awards to the feature being analyzed.

- Relevance is a value between 0 (minimum) and 10 (maximum), which determines how important the analyzed feature is to fulfill a given need.

Below is an example calculation for the question: *"Satisfaction with the reliability of the last trolley purchased"*: In this case, a 50% score has been obtained, and it is noted that this characteristic affects up to 3 of the requirements to be met by the product, namely ease of maintenance (with an importance of 8 out of 10), use of quality materials (10 out of 10) and robustness and stability (4 out of 10). The calculation for the first requirement (ease of maintenance) can be consulted in Equation 4.

$$N - C = (1 - 0.5) \cdot \frac{8}{10} = 0.4 \qquad (4)$$

3.2 Definition of functions and redesign (second phase VAM-2P)

As an intermediate step to continue with the second phase, a detailed analysis of the functions of the trolley to be redesigned is carried out using the following sub-phases: i) intuitive research, ii) analysis of sequences, iii) stress analysis, and iv) study of the environment, from which the most important functions are identified (see Table 3). The inputs for Table 2 are the relevance of the function regarding the need (from 0 to 5, (Eq. 1)) and the weight in percentage of the need as calculated on (Eq. 4) and compared with the rest of them (PT_I). The outputs are on the Table 3 as the weight in percentage of the function's value.

In this case study, a simplistic analysis of the initial survey data shows that ensuring operator ergonomics provides the most value in meeting perceived needs, while aspects of trolley manufacture have less perceived value. In summary, the VAM-2P was used to identify the functions that require improvement. The two primary functions that should be considered during the redesign process, in order of importance, are: i) ensuring operator ergonomics, and ii) optimizing the overall design. After a brainstorming session, four alternatives for our harvesting trolley were developed (Fig. 3).

Table 2. Functions/needs matrix, adapted from IAT's Value Management Manual [5]. Complete example from the case study where: functions are listed in abscesses, needs appear on ordinates, VTF is the total value of the function presented both on summatory and percentage weight with peers and Imp. is the importance of the need in the product.

Nec. / Func.	FI	FII	FIII	FIV	FV	FVI	FVII	FVIII	FIX	FX	FXI	% Imp.
NI	5	4	4	2	5	0	2	4	1	0	1	25.38
	1.27	1.02	1.02	0.51	1.27	0	0.51	1.02	0.25	0	0.25	
NII	0	2	1	2	1	2	5	4	5	3	5	12.57
	0	0.25	0.13	0.25	0.13	0.25	0.63	0.50	0.63	0.38	0.63	
NIII	0	4	3	4	2	1	1	5	3	1	1	5.91
	0	0.24	0.18	0.24	0.12	0.06	0.06	0.30	0.18	0.06	0.06	
NIV	0	0	2	0	2	5	5	1	2	4	5	11.70
	0	0	0	0.23	0	0.23	0.59	0.18	0.23	0.47	0.59	
NV	2	4	4	5	5	1	0	0	2	0	0	2.50
	0.05	0.10	0.10	0.126	0.126	0.03	0	0	0.05	0	0	
NVI	0	1	0	2	2	3	4	1	5	3	4	13.74
	0	0.14	0	0.28	0.28	0.41	0.55	0.14	0.69	0.41	0.55	
NVII	3	4	2	4	4	5	4	1	3	5	1	5.37
	0.16	0.22	0.11	0.22	0.22	0.27	0.22	0.05	0.16	0.27	0.05	
NVIII	5	2	2	3	5	1	0	3	4	1	3	7.39
	0.37	0.15	0.15	0.22	0.37	0.07	0	0.22	0.30	0.07	0.22	
NIX	5	5	4	5	5	4	2	1	4	4	0	15.44
	0.77	0.77	0.62	0.77	0.77	0.62	0.31	0.15	0.62	0.62	0	
VFT	2.62	2.88	2.53	2.60	3.50	2.29	2.83	2.50	3.11	2.28	2.35	29.51
% VFT	**8.89**	**9.74**	**8.56**	**8.82**	**11.87**	**7.77**	**9.67**	**8.47**	**10.52**	**7.72**	**7.97**	100

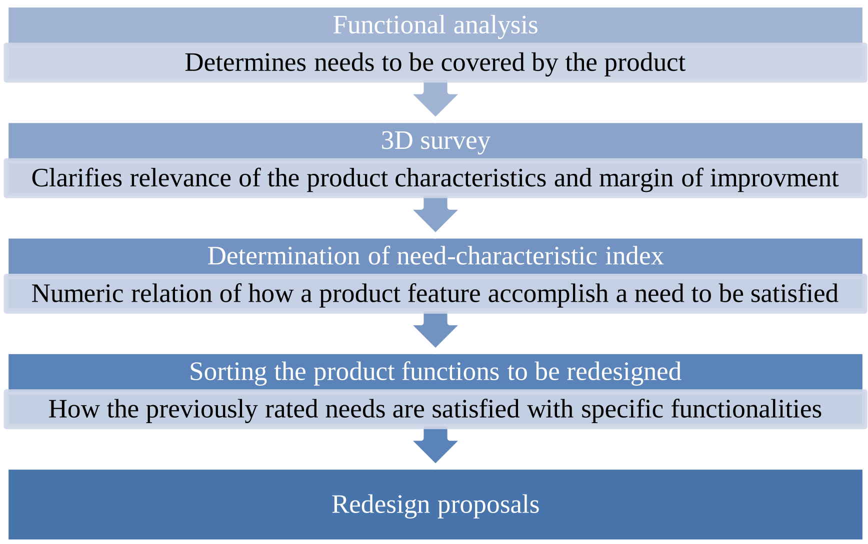

Fig. 2. Detailed pipeline of the VAM-2P 1st step

Table 3. Relative importance of the trolley functions that require redesigning.

Position	% Value	Function
1	11.87	Ensure operator ergonomics
2	10.52	Design optimization
3	9.74	Carrying a load
4	9.67	Ease of maintenance
5	8.89	Transportation of Boxes
6	8.82	Rigid and Stable Structure
7	8.56	Movement
8	8.47	Ancillary Equipment
9	7.97	Use of similar/standard parts
10	7.77	Durable
11	7.72	Use of suitable materials

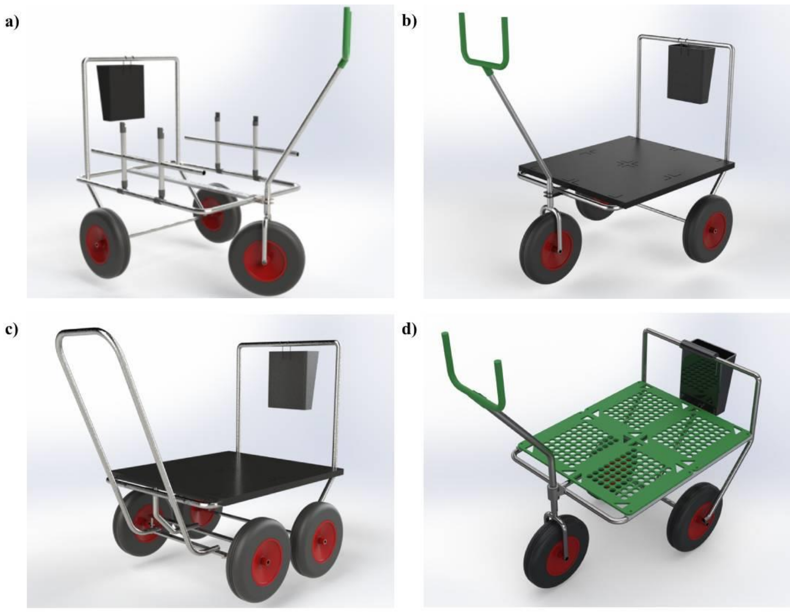

Fig. 3. Alternatives proposal: a) Alternative 1, with foldable platform for versatility; b) Alternative 2, with plastic platform to cut costs and directional wheel for ergonomics; 2c) Alternative 3, with four wheels, plastic platform and steering system for ergonomics, and d) final proposal of redesign.

3.3 Environmental vector (circularity of design and product)

One proposed improvement was to add light platforms to ensure the loads and reduce the steel construction. In this last phase, this plastic material will be optimised following a sustainability criterion. The circularity analysis examines four key indicators regarding environmental impact assessment: carbon footprint, energy consumption, air acidification, and eutrophication. In order to speed up the process on this conceptualization, the alternative material, polyethylene high density (PEHD), containing the environmental indicators required for the environmental impact comparison, was selected out of the internal SolidWorks database. Some boundary conditions are set to define the impact: i) 20 years of estimated product life, ii) manufacturing in Asia and ship transport to Europe as destination, and iii) 66% of recycling after the end of life.

As can be seen in Figure 4, the sustainability analysis showed that PEHD is a better alternative in terms of environmental impact and preservation of the original design mechanical performance. Moreover, PEHD is a recyclable material with adequate chemical resistance and is suitable for the required manufacturing process. This is evidenced by the reduction of the 4 circularity indices (carbon footprint, total energy consumption, atmospheric acidification, and life cycle water eutrophication) in reference to the original PVC component.

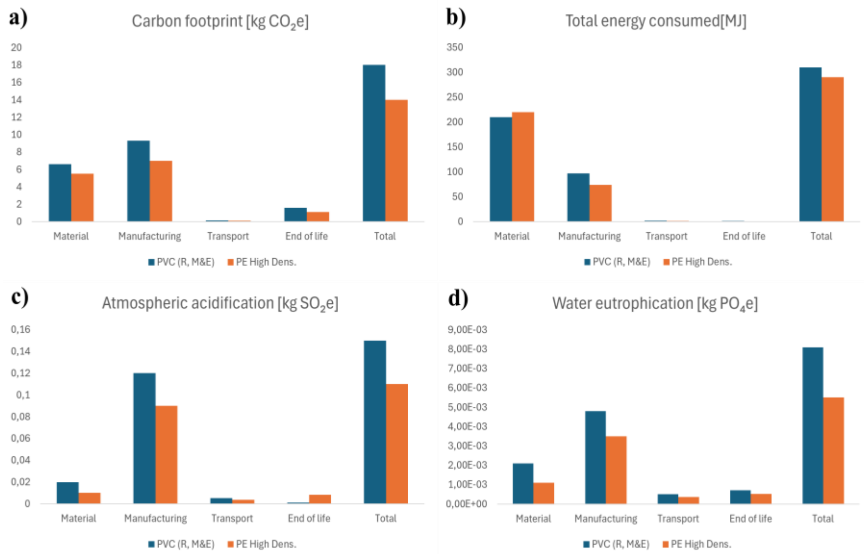

Fig. 4. Graphic comparison between the environmental impact of PEHD versus the previously proposed PVC. The life cycle assessment, done with the Sustainability module of SolidWorks 3D CAD®, showed the following reductions on the studied indicators: -22% on a), -6% on b), -27% on c) and -32% on d).

4 Conclusions

As demonstrated by the developed case study, the proposal based on an adaptation of the two-phase value analysis methodology (VAM-2P), including the environmental vector, is a valuable tool for introducing students to design-driven innovation through examples of redesigning real-life products. To increase the motivation of the students, they can be encouraged to use the tools provided by the local office of trademarks and intellectual property (e.g., Spanish Patent and Trademark Office - www.oepm.es -) to register the innovation achieved, if any, through the redesign of the product, while also tracking the quality of the design process by surveying the same panel about said proposals.

This approach aligns with SDG 4 (Sustainable Development Goals) and Target 4.4 of the 2030 Agenda for Sustainable Development [9]. The aim is to solidify this tool as a mechanism used to increase the acquisition of necessary skills to access and promote entrepreneurship among young people and adults. In this sense, students will be ensured to be equipped with the necessary skills to meet the needs of the industry.

4.1 Limitations and future lines

There are several limiting factors in the development of this proposal, two of which stand out above the rest: the target participants of the survey can be hard to reach out by students, and the determination of the characteristics and functions of the product. A wrong approach to any of these aspects can lead to redesigning proposals that lack real value in terms of innovation.

It is proposed to introduce in the agenda of Higher Education the incorporation of a new subject in both branches of Engineering Degrees, industrial and agricultural, to meet the needs of the new paradigm of the circular economy, providing students with the opportunity to acquire basic notions about design processes and innovation of products and services.

Acknowledgements

To the Junta de Andalucía for the postdoctoral contract (ref. DOC_01126) of the second author, coordinator of the research line in which this study is framed "Applications of design (spatial, industrial, graphic, ...) and product development in the agri-food sector and the new paradigm of the circular economy". We are also grateful for the support we received from the RNM-368 group (Topics: Computer Aided Design, Remote Sensing and Engineering Graphics) of the University of Almeria. Finally, it should be noted that this work is part of the general lines of research promoted by the Campus of International Agri-food Excellence ceiA3, Spain (http://www.ceia3.es/es).

References

1. González-Yebra, Ó.; Aguilar, M.A.; Aguilar, F.J. Is the design a vector to be considered in the agri-food industry? An interprofessional analysis in Andalusia (Spain). In Advances on Mechanics, Design Engineering and Manufacturing II, pp. 610-621. Lecture Notes in Mechanical Engineering. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-12346-8_59
2. Arroyo-Vázquez, M.; González-Yebra, Ó.; Pacheco-Blanco, B.; Artacho-Ramírez, M.Á. Analysis of the perception and presence of design in the fruit and vegetable cluster: The case

of southeast Spain. Agric. Econ. - Czech, 69(8), 321-331 (2023). https://doi.org/10.17221/169/2023-AGRICECON
3. Martin-Doñate, C.; Lucena-Muñoz, F.; García-Cabrera, L.G.; Mercado-Colmenero, J.M. Generation of Entrepreneurship Environments for New Product Development. In Advances on Mechanics, Design Engineering and Manufacturing III, pp. 366-371. Lecture Notes in Mechanical Engineering. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-70566-4_58
4. AENOR. UNE 144001:2007 IN. Gestión del valor. Guía para el diseño y desarrollo de proyectos de Análisis del Valor de acuerdo a la Norma UNE-EN 12973:2000 "Gestión del Valor". Asociación Española de Normalización y Certificación (Spanish Standardization and Certification Association), Madrid. Available at: https://n9.cl/y1gaa
5. Gómez Mirón, H.; Luque Olmedo, M.A. Manual de gestión del valor: Mejora de la Calidad sin aumento de costes, reducción de costes sin pérdida de Calidad. Instituto Andaluz de Tecnología (IAT), Sevilla, España (1998). ISBN: 84-923464-0-X
6. Torcătoru, C.; Săvescu, D.; Repanovici, A. Literature review by scientometric methods on the impact of the circular economy on sustainable industrial products. Sustainability, 14(9), 5084 (2022). https://doi.org/10.3390/su14095084
7. González-Yebra, Ó.; Lozano Rey, A.; Tolón Becerra, A.; Takeuchi, C. P. El bambú Tonkin (Pseudosasa amabilis) como material a explorar en el Ecodiseño. El diseño de un puesto de mercado como caso de estudio. Maderas-Cienc Tecnol, 26, 1-14 (2024). https://doi.org/10.22320/s0718221x/2024.05
8. Vinodh, S.; Jayakrishna, K.; Alegria, D. Environmental impact assessment of an automotive component using eco-indicator and CML methodologies. Clean Technol Envir, 14(2): 333-344 (2012). https://doi.org/10.1007/s10098-011-0405-x
9. United Nations. (n.d.). Department of Economic and Social Affairs. Sustainable Development. 17 Goals. https://sdgs.un.org/goals