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CONSTRUCTION OF SCALE MODELS IN INDUSTRIAL DESIGN: THE IRRUPTION OF ADDITIVE MANUFACTURING. RUBRICS PROPOSAL FOR AN OBJECTIVE EVALUATION

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Abstract

Recent studies corroborate the progressive implementation of Additive Manufacturing technologies (commonly known as 3D printing) in education, demonstrating several advantages. In the field of industrial design, the development of models during the design phase of product design helps designers in training to visualize their proposals. Today, 3D printing and traditional model-making techniques coexist in classrooms. With both techniques it is possible to achieve good results, but when it comes to evaluating them it is not so simple, since both ways of working are different and apparently the same evaluation criteria cannot be used in both cases, which could lead to comparative grievances.

This work presents a series of rubrics that can help to evaluate the student's models in an objective way and under equal conditions, independently of the technique used: traditional o 3D printing. In order to do this, we started from a rubric made to evaluate traditional models, which was tested during a couple of academic years in another subject. This rubric was adapted to create a new rubric, which allowed to evaluate models made by 3D printing, looking for equivalent criteria with the previous rubric to guarantee a fair evaluation of both ways of working.

The rubrics were tested experimentally in the subject 'Prototypes: experimental workshop', taught during the 4th year of the Bachelor's Degree in Industrial Design and Product Development Engineering at the Universitat Jaume I (Spain). Two groups of users assessed each work using these rubrics. The results showed, on the one hand, that both groups found it easy to evaluate the works using these rubrics, and on the other hand, that these rubrics allow for a fairly objective evaluation of the works, since the score obtained by both groups of users was very similar.

Keywords: Industrial design, additive manufacturing, 3D printing, rapid prototyping.

1 INTRODUCTION

Additive Manufacturing technology (hereinafter 3D Printing) is increasingly common in various fields, due to the lower cost of its components and its ease of use. Recent studies corroborate the progressive implementation of this rapid prototyping technology also in teaching, in fields such as architecture [1] and engineering [2] [3], demonstrating that it can boost the creativity of students [4] and their cognitive enhancement [5].

In the field of industrial design, the development of models during the planning phase of product design helps designers in training to visualise their proposals [6]. Today, 3D printing and traditional model-making techniques coexist in classrooms. With both techniques it is possible to achieve good results, but when it comes to evaluating them it is not so simple, since both ways of working are different and apparently the same evaluation criteria cannot be used in both cases, which could lead to comparative grievances.

In the subject 'Prototypes: experimental workshop', taught during the 4th year of the Bachelor's Degree in Industrial Design and Product Development Engineering at the Universitat Jaume I (Spain), students learn to propose design solutions related to the habitat, building scale models and small prototypes. This subject offers the possibility of improving both the planning of the design process and the creative practice in industrial design. Through the development of different and varied design proposals directed towards achieving a more complete design project, the students will be able to define product designs from the conceptual phase to the development phase. The course is closely related to the second year 'Modelmaking Workshop', since both share the same basic approach, and each of them corresponds to two moments or stages of the design process.

Until now, traditional techniques were used, such as modelling, carving and construction, using materials such as wood, plastic and metal. But recently additive manufacturing equipment (popularly known as 3D printers) was acquired to give the student alternative tools to visualize and build new shapes. The acquired equipment uses the technology called Fused Filament Fabrication (FFF), very popular in the market of rapid prototyping.

The introduction of 3D printing in the subject presented the challenge of how to evaluate these works objectively, since criteria used for the evaluation of models made using traditional techniques, such as cutting quality, welding or manual bending of the material, were not applicable here.

This work describes the process of elaborating some rubrics that can help to evaluate the student's models objectively and under equal conditions, independently of the technique used.

2 METHODOLOGY

For the elaboration of a rubric that would allow an objective and impartial evaluation of the construction of models by means of 3D printing, a rubric previously created by the authors to evaluate traditional models was first taken as a starting point, adapting it to the current subject.

2.1 Creation of the rubric to evaluate models built using traditional techniques

The rubric was constructed to evaluate two aspects of the model: the concept and the construction. In addition, each aspect was evaluated through various criteria.

2.1.1 Criteria for the evaluation of model construction

- Proper material selection: considers whether the materials selected by the designer for the model or prototype are suitable for simulating real materials (cardboard, wood, metal, plastic).
- Precision of the cutting of the pieces: it evaluates if the pieces have been cut of suitable form, or if there is some dimensional deviation by having used a not very precise tool.
- Precision of the bending of the pieces: it evaluates if the pieces have been bent in an adequate and precise way, or if wrinkles have appeared in the piece due to a bad bending operation.
- Precision in the application of the adhesive and/or welding: it evaluates if the quantity of adhesive applied to join the different pieces is excessive, sufficient or scarce, and if it protrudes in some points. The accuracy of the welding application is also evaluated.
- Structural integrity during manipulation: it evaluates whether the model can be manipulated in a normal way by a user without its parts being accidentally uncoupled or detached.
- Surface finishing and/or painting: evaluates possible defects or unwanted irregularities on the surface. It also takes into account the application of the paint (if it is excessive and the brushstrokes are noticeable, or if it is scarce and you can see the material below) and if the colours chosen are correct for the type of product.
- Cleanliness: the final cleanliness of the model or prototype is evaluated, examining whether there are dirt stains or the remains of any drawing instrument used during the work process to delimit cutting or gluing areas, such as pencils, pens or markers.

2.1.2 Criteria for the concept evaluation

- Formal design: it evaluates if the group of the different parts is adequate, balanced, harmonic and attractive.
- Functional design: evaluates the functionality of the idea, i.e. whether the designed product would be able to perform the intended functions, and whether the solution is feasible or realistic.
- Ergonomic design: evaluates if the real size version of the design would be easy to use, or if on the contrary the proportions, sizes and distances of its different parts would make its use impossible.

2.2 Creation of the rubric to evaluate models built using 3D printing.

From the beginning, the aim was to create a rubric that would be equivalent to the one used to evaluate models built using traditional techniques. The objective was that both rubrics would allow to emit a evaluation as complete and as fair, independently of the way of constructing the models. Many of the criteria used in the previous rubric were equally valid to evaluate the models built using 3D printing, so they were added to the new rubric. Other criteria were also added that were important to evaluate certain aspects present only in this type of models.

2.2.1 Criteria for the evaluation of model construction

- Proper preparation of digital files for printing (format, print size, file...): evaluates whether the files are in the right format, with the right polygon geometry and whether the print size is adequate for the limitations of the 3D printer.
- Wall thicknesses suitable for 3D printing. Consider that the thicknesses used are optimized so that they are not fragile or use an excessive amount of material.
- Positioning and support structure appropriate to the geometry of the piece and the technique used. Consider that the piece can be built preferably without using support structures, or alternatively use strategies such as changing the orientation of its manufacture or divide the piece into parts to optimize its printing.
- Adequate selection of the printing material: it considers whether the choice of the printing material is adequate for the geometry, detail and structural complexity of the proposal, considering the different characteristics of hardness, flexibility or printing temperature (ABS, PLA, PETG, Nylon, TPE, PC, etc.).
- Selection of the best temperature (filament and bed) and printing speed: considers the choice of the most appropriate temperature and speed according to the material chosen and the complexity of the shape.
- Adhesive application precision: evaluates if the amount of adhesive applied to join the different pieces is excessive, sufficient or scarce, and if it protrudes in some points.
- Structural integrity during handling: evaluates whether the model can be handled normally by a user without its parts being accidentally uncoupled or detached.
- Surface finishing and/or painting: evaluates possible defects or unwanted irregularities on the surface. It also takes into account the application of the paint (if it is excessive and the brushstrokes are noticeable, or if it is scarce and you can see the material below) and if the colours chosen are correct for the type of product.
- Cleanliness: the final cleanliness of the model or prototype is evaluated, examining whether there are dirt stains or the remains of any drawing instrument used during the work process to delimit cutting or gluing areas, such as pencils, pens or markers.

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2.3 Equivalence of criteria

The following table compares the criteria that were used for the elaboration of both rubrics. Some criteria are independent of the construction technique of the model and therefore appear in both rubrics. Others, on the other hand, apply only to one of the two means of construction.

Table 1. Equivalence of criteria

Criteria for evaluating models constructed using traditional techniques	Criteria for evaluating models built using 3D printing
-	Proper file preparation
-	Wall thicknesses
-	Positioning and support structure
-	Proper selection of temperature and speed
Proper selection of material	Proper selection of the printing material
Precision of the pieces cutting	-
Precision of the pieces bending	-
Precision in the application of the adhesive / welding	Precision in the application of the adhesive
Structural integrity during handling	Structural integrity during handling
Surface finishing and/or painting	Surface finishing and/or painting
Cleanliness	Cleanliness
Formal design	Formal design
Functional design	Functional design
Ergonomic design	Ergonomic design

3 RESULTS

This section presents the two final rubrics. In the subject for which they were created, the skills for model construction are very important, therefore it was decided to give a value of 70% to the criteria related to the evaluation of the technical elaboration of the model, and 30% to the rest of the criteria.

3.1 Rubric for the evaluation of models made using traditional techniques

Criteria for the evaluation of the technical elaboration of the model (70% of the grade):

Proper selection of material	The materials of the model are not at all adequate and simulate very badly the real materials	◀	1	2	3	4	5	▶	The materials in the model are very suitable and simulate real materials very well
Precision of the pieces cutting	The cutting is quite imprecise and irregular	◀	1	2	3	4	5	▶	The cutting is very precise
Precision of the pieces bending	Many pieces are bent inaccurately and wrinkles are visible	◀	1	2	3	4	5	▶	The pieces are bent very precisely and no wrinkles are visible
Precision in the application of the adhesive / welding	The adhesive or welding protrudes in many points, and in others it is scarce	◀	1	2	3	4	5	▶	The adhesive or welding is applied where it should, and does not protrude at any point
Structural integrity during handling	Parts of the model can be easily dismantled during handling	◀	1	2	3	4	5	▶	The model is held very tightly together and stable when manipulated

Surface finishing and/or painting	It has a lot of defects on the surface, or the color combination is not right at all. You can see a lot of the brushstrokes and the material underneath	◀	1	2	3	4	5	▶	The surface finish is very good and well coordinated in colors. You can't see any brushstrokes or the material underneath
Cleanliness	At a glance there are many stains, or pencil, pen or marker lines	◀	1	2	3	4	5	▶	No stain or mark of pencil, ball-pen or marker is visible

Criteria for the evaluation of the concept (30% of the grade):

Formal design	It does not use the shapes in a balanced or harmonic way. The composition is unattractive	◀	1	2	3	4	5	▶	Use these shapes in a very balanced and harmonious way. The composition is appropriate and very attractive
Functional design	The idea is not functional at all, and suggests an almost impossible or very unrealistic solution	◀	1	2	3	4	5	▶	The idea is very functional, and suggests a very sensible and realistic solution
Ergonomic design	Its full-size version wouldn't be easy to use or ergonomic	◀	1	2	3	4	5	▶	Its full-size version would be ergonomic, very easy and comfortable to use

3.2 Rubric for the evaluation of models made using 3D printing

Criteria for the evaluation of the technical elaboration of the model (70% of the grade):

Proper file preparation	The files are not in the proper format and the print size is not adequate for the limitations of the 3D printer.	◀	1	2	3	4	5	▶	Files are in the proper format and print size is appropriate for the limitations of the 3D printer
Suitable wall thicknesses	The walls of the digital model are thin and cannot be built or are very weak and fragile.	◀	1	2	3	4	5	▶	The walls of the geometric model have an adequate thickness with optimal dimensions.
Suitable positioning and support structure	The geometry of the piece is not correctly oriented. Supports are generated that with another orientation or dividing the part would not be necessary.	◀	1	2	3	4	5	▶	The position and orientation are adequate and optimized. The supports are unavoidable due to the complexity of the piece.
Selection of the best printing temperature and speed	The chosen temperature and printing speed have caused many problems in the final result.	◀	1	2	3	4	5	▶	The chosen temperature and printing speed did not cause any problems.

Proper selection of material for printing	The choice of printing material is not suitable for the complexity of the proposal (hardness, flexibility and printing temperature)	◀ 1 2 3 4 5 ▶	The choice of printing material is very suitable for the complexity of the proposal (hardness, flexibility and printing temperature)
Precision in the application of the adhesive	The adhesive protrudes in many points, and in others it is scarce	◀ 1 2 3 4 5 ▶	The adhesive is applied where it should, and does not protrude at any point
Structural integrity during handling	Parts of the model can be easily dismantled during handling	◀ 1 2 3 4 5 ▶	The model is held very tightly together and stable when manipulated
Surface finishing and/or painting	It has a lot of defects on the surface, or the color combination is not right at all. You can see a lot of the brushstrokes and the material underneath. The steps of the layers can be perceived.	◀ 1 2 3 4 5 ▶	The surface finish is very good and well coordinated in colors. You can't see any brushstrokes or the material underneath and the various layers are not noticeable.
Cleanliness	At a glance there are many stains, or pencil, pen or marker lines	◀ 1 2 3 4 5 ▶	No stain or mark of pencil, ball-pen or marker is visible

Criteria for the evaluation of the concept (30% of the grade):

Formal design	It does not use the shapes in a balanced or harmonic way. The composition is unattractive	◀ 1 2 3 4 5 ▶	Use these shapes in a very balanced and harmonious way. The composition is appropriate and very attractive
Functional design	The idea is not functional at all, and suggests an almost impossible or very unrealistic solution	◀ 1 2 3 4 5 ▶	The idea is very functional, and suggests a very sensible and realistic solution
Ergonomic design	Its full-size version wouldn't be easy to use or ergonomic	◀ 1 2 3 4 5 ▶	Its full-size version would be ergonomic, very easy and comfortable to use

3.3 Implementing the rubrics

Some students chose to make their models using 3D printing, while others chose traditional construction techniques and materials (modeling, carving and construction). The quality of the works presented showed that with both technologies good results can be achieved, if work is done properly (Figure 1).

Figure 1. Models created by students using traditional techniques (1: Diana Gabriela Voicu (modeling), 3: Salvador Fuster Fayos (carving), 5: Salvador Balaguer Mir (construction)) and by 3D printing (2: David Gómez Picazo, 4: Enrique Cerdá Signes, 6: Diana Gabriela Voicu)

The rubrics were applied experimentally in the subject during the current academic year. Two groups of users assessed each work: first the students and then the teachers. This double assessment allowed two conclusions to be reached: firstly, both groups found it easy to evaluate the work using these rubrics; secondly, the grade obtained by both groups was very similar, which shows that both rubrics allow for a fairly objective evaluation of the work.

4 CONCLUSIONS

3D printing and traditional model making techniques now coexist in classrooms, and it is clear that both technologies can achieve good results. The development of models during the design phase of product design helps designers in training to visualize their proposals. The rubrics presented here can help to evaluate their work objectively and under equal conditions, regardless of the technique used.

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REFERENCES

[1] M. Valiente López, M.C. Sanz Contreras, S. Moyano Sanz, and J.R. Osanz Díaz, "BIM and 3D impression" in *ICERI2017 Proceedings*, 17-24. IATED, 2017

[2] J. Ferreiro-Cabello, E. Fraile-García, M. Corral-Bobadilla, and R. Lostado-Lorza, "Teaching innovation project based on 3D printer for the elasticity and strength of materials subject in the degree of mechanical engineering" in *EDULEARN16 Proceedings*, 6441-6446. IATED, 2016

[3] J. Formanek, and J. Jirasko, "Engineering design project of a gripper for robots manufactured by a 3D printer" in *INTED2018 Proceedings*, 1308-1312. IATED, 2018

[4] J.P. Bécar, J. Vareille, V. Cayez, and Y. Notteau, "3D printing is boosting the student's creativity" in *ICERI2017 Proceedings*, 1817-1823. IATED, 2017

[5] S. Mori, J. Niewint, and C. Beni, "Cognitive enhancement and 3D printer in kindergarten: an exploratory study" in *ICERI2018 Proceedings*, 2388-2392. IATED, 2018

[6] F. Felip, M.L. García, and S. Martín, "The use of rubrics to evaluate the construction of scale models in the university teaching of industrial design", *EDULEARN18 Proceedings*, 1444-1451. IATED 2018