A Successful Partnership for the Development of a Laboratory Friction Testing Apparatus: A Project Review

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Abstract — *There are several useful parameters to evaluate the quality and applicability of fabrics. The coefficient of friction is one of them, being one of the most important factors to objectively evaluate the concept usually known as handle.*

This paper will summarize all the conceptual design phases that were carried out for the study, development and construction of a laboratory testing apparatus for computing the friction coefficient of 2D soft materials such as fabrics, either woven or knitted, non-wovens and commonly used soft paper materials, usually known as tissues.

These activities have been undertaken at the Mechatronics Laboratory at the University of Minho, School of Engineering, which gathered senior researchers and MSc graduation students from the departments of Mechanical and Textile Engineering and from the Integrated Master courses in Mechanical, Textile, Electronics, Materials and Biomedical Engineering.

This research and development study is of a mechatronics-based project, which has been financed by the Portuguese Agency for Innovation (AdI). The project outcome was an equipment named FRICTORQ, designed to measure the coefficient of friction in fabrics and other planar flexible surfaces, integrating a high sensitivity torque sensor (with a data acquisition system), a DC motor (with a gear reducer and a timing belt to drive the rotating support of the sample) and a software application to control the whole system.

This equipment has been initially redesigned (from FRICTORQ I to II) and these two versions have been used by several MSc and PhD researchers in the mechanical, textile, materials and biomedical areas, whose results were used for the validation of the equipment and in the prediction of the handle of some materials used and touched by humans. Many of the obtained results have already been presented in international conferences or published in well accredited specialised journals.

In order to extend its application, a new redesign of the equipment is underway, which will enable the measurement of the friction coefficient of fabrics, or other planar flexible surfaces, in a liquid environment, such as water, for example. Further extensive experiments will validate this new upgrade.

In this paper some of the results obtained with FRICTORQ II, mainly in the evaluation and development of new materials to be used in biomedical applications, will also be presented and discussed.

Index Terms — *Competency-based education, Experimental techniques and analysis (FRICTORQ), Mechatronics design, modelling and simulation techniques.*

INTRODUCTION

Most textile materials are used near humans and frequently touched by the human skin and by the human hand in particular, namely clothing, home furnishings and automotive fabrics, either woven, knitted or non-wovens. Other materials, such as commonly used soft papers, known as tissues, also play an important role in our day-to-day life since they can be used in contact with different parts of the human body. The coefficient of friction is therefore one of the factors involved in the so-called *fabric hand* parameter and its importance justifies the number of contributions given in the past to this problem [1]-[7]. A new method to characterise the coefficient of friction of textile fabrics has been proposed by the authors [8]-[19] and the first ever developed prototype, named FRICTORQ (after the acronym for **Fric**tion **Torq**ue Tester), is protected by the Portuguese Patent Nº. 102790, entitled "Método e Aparelho para a Determinação do Coeficiente de Atrito de Materiais Sólidos Planos" ("Method and Apparatus for Determining the Friction Coefficient of Solid Planar Materials"), from 12 June 2002.

As mentioned, this testing laboratory equipment has been used by several MSc and PhD researchers in the mechanical, textile, materials and biomedical knowledge areas, whose results were used for the validation of the equipment, as well as on its redesign, and in the prediction of the *handle* of some materials touched by humans.

The objective of this whole project is to develop a friction testing apparatus to enable a quantitative assessment of the *touch/handle*, in order to predict the comfort behaviour of 2D structures when used or touched by humans.

THE FRICTORQ TEST RIG MODELS

Three different FRICTORQ test rig models have been designed and developed so far, and the following topics will resume all the research and developments undertaken by the authors to build up a new friction tester prototype, to accomplish the objectives previously mentioned.

FRICTORQ I

The principle of the original FRICTORQ tester is based on the dry clutch, where an annular shaped flat upper body (that is kept still) rubs against a lower flat surface, which rotates around a vertical axis at a constant angular velocity. The friction coefficient between the two contacting surfaces is then proportional to the level of the dragging torque between them, measured by means of a precision reaction torque sensor. Contact pressure is constant, given by the own weight of the upper body. The signal from the torque sensor is digitalised through an electronic interface and fed into a PC where the friction coefficient is worked out. A schematic representation of the acquisition, command and control system of the whole friction testing apparatus can be observed in Figure 1.

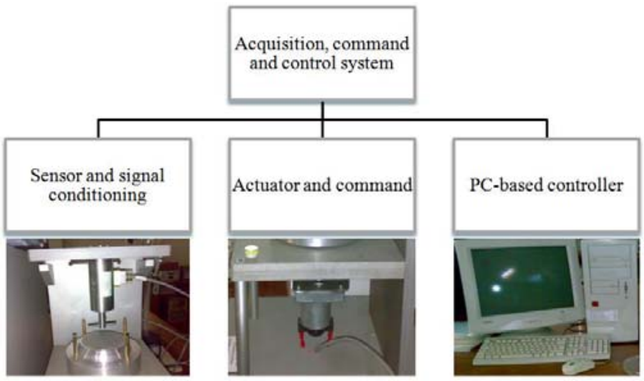


FIGURE 1
SCHEMATIC REPRESENTATION OF THE ACQUISITION, COMMAND AND CONTROL OF THE FRICTORQ TESTER

Figures 2 and 3 present the first developed friction tester, in which the upper fabric rubs against a horizontal flat lower fabric. This same tester was modified to accommodate a steel-to-fabric working principle, instead of the testing arrangement shown in Figure 3. Figure 4 depicts a detail of this new friction area, in which the upper body comprises a smooth or textured metallic body with dimensions of ∅50/40 mm, producing a distributed pressure of 3,5 kPa – see Figure 5 for a detailed close-up of the two metallic bodies.

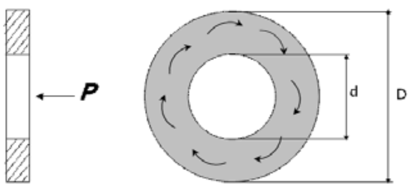
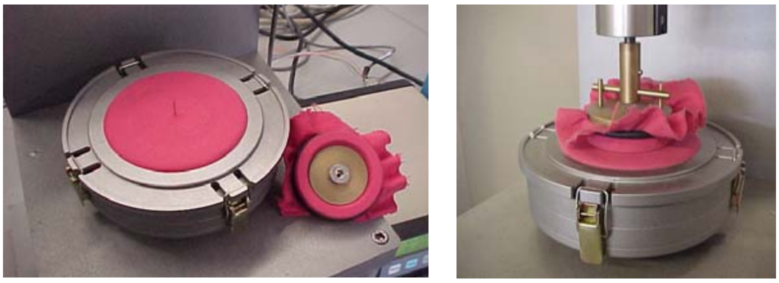


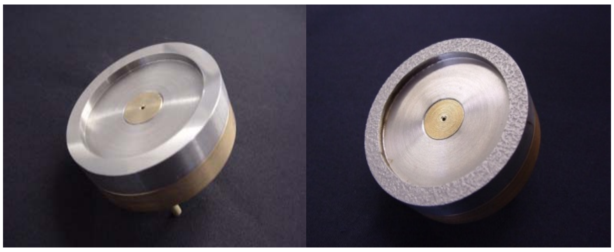
FIGURE 2
GEOMETRY OF THE FIRST ADOPTED THEORETICAL MODEL FOR THE FRICTORQ I



(A) (B)

FIGURE 3
THE FIRST DEVELOPED TEST RIG (FRICTORQ I): DETAIL VIEWS OF BOTH TESTING SAMPLES (A) POSITIONED AND ATTACHED BY THE TIGHTENING FABRIC CLAMPS AT THE BEGINNING OF THE FRICTION TEST (B)

FIGURE 4
THE STEEL-TO-FABRIC WORKING PRINCIPLE USED IN FRICTORQ I



(A) (B)

FIGURE 5
FINAL ADOPTED ANNULAR SHAPED UPPER BODY USED IN THE FRICTORQ I MODEL: DETAIL OF THE SMOOTH (A) OR TEXTURED (B) METALLIC BODIES

A typical result, obtained using the rubbing principle highlighted in Figure 4 and with the textured metallic body in Figure 5(B), is presented in Figure 6. The first peak is related to the static friction coefficient and all the other computed parameters are displayed on the right hand side of the software front panel shown: Kinetic friction coefficient, maximum and mean torque measured and total number of collected data points.

FRICTORQ II

The first FRICTORQ model (Figure 4) went through various development stages and in a recent version the contact between the 2D sample and the instrument was restricted to three small special elements (or feet), radially disposed at 120°. This new arrangement provides, during the test, a relative displacement of approximately 90º, assuring that a new portion of the sample is always moved under the contact elements.

A schematic representation of the latest adopted model named FRICTORQ II is highlighted in Figure 7, which also details the upper body that includes three small pads with an approximately square shape, covered by a number of calibrated steel needles of 1 mm diameter. It must be noticed that the rotary action remained the same as in the previous model and that the contact pressure on the fabric samples was set to 3,5 kPa and the linear velocity in the geometric centre of each contact element was approximately 1,5 mm/s.

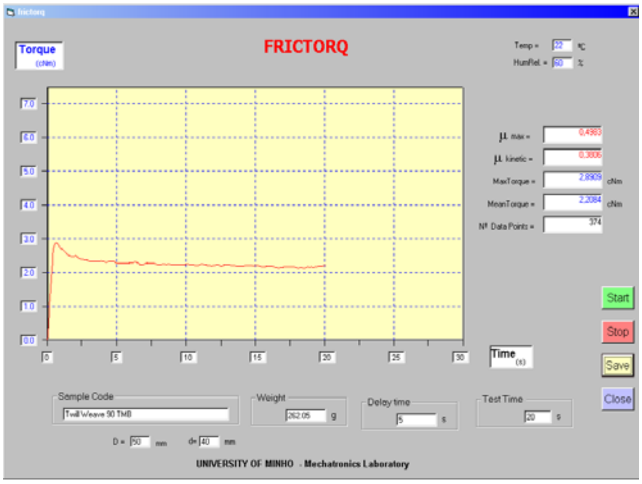
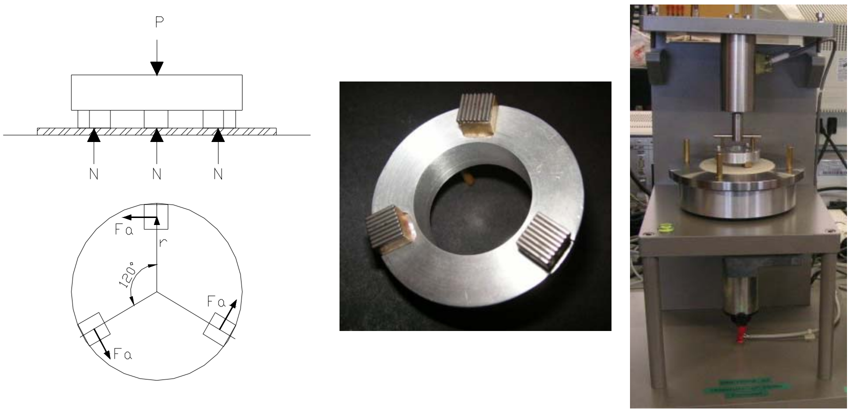


FIGURE 6
A TYPICAL GRAPHICAL OUTPUT OBTAINED WITH FRICTORQ I IN A STEEL-TO-FABRIC ARRANGEMENT, USING THE TEXTURED METALLIC BODY SHOWN IN FIGURE 5 (B)



(A) (B) (C)

FIGURE 7
FRICTORQ II: (A) THE LATEST ADOPTED MODEL FOR THE FRICTION TESTER; (B) DETAIL VIEW OF THE UPPER CONTACT BODY, WITH THREE SMALL SQUARE SHAPED PADS, AND (C) FINAL TESTING ARRANGEMENT

FRICTORQ III

The latest developments carried out will enable the measurement of the friction coefficient in a liquid environment, such as water, for example. After identifying the purpose of the outcome and the functions and sub-functions to be achieved in this design problem, the team efforts were divided into two fundamental aspects:

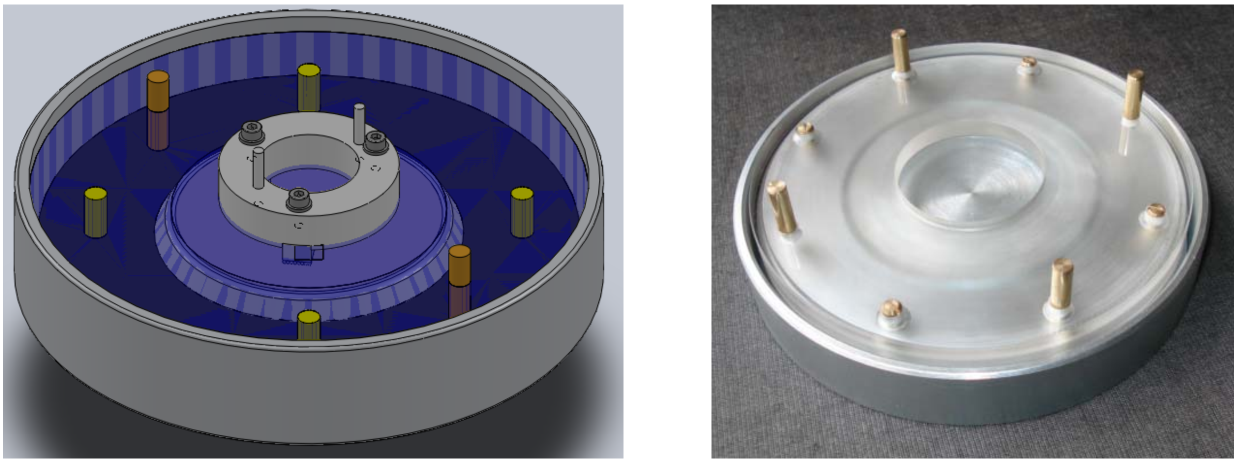
- On the design of a new container for the liquid environment testing, and
- On the design of a new upper contact body, maintaining the contact pressure on the fabric samples of 3,5 kPa.

To accomplish this objective, not only the two latter elements had to be designed and manufactured, but also two new pressure and centring rings had to be redesigned and manufactured, to keep the testing specimens in place and stretched and to center the upper body containing the reference surface with the sample and the torque sensor. Figure 8 displays a virtual 3D model of this new add-on FRICTORQ function, carried out using a commercially available CAD software, as well as the manufactured assembled components to be coupled to the FRICTORQ II model of Figure 7(C).

... Further Developments

Two further developments are being undertaken to provide additional features to the testing apparatus:

- The first one is addressed to the redesign of the contact elements shown in Figure 7(B), to accommodate a special polymer in the contact face to simulate the (*touch/handle* of the) human skin, and
- The second one, being carry out at the Technical University of Liberec (in Czech Republic), will enable systematic tests varying the temperature of the contact elements, as a new cost-effective add-on function to equip the FRICTORQ II model; this new testing apparatus will be named FRICTORQ IV.



(A) (B)

FIGURE 8
FINAL ADOPTED FRICTORQ III MODEL TO MEASURE FABRIC FRICTION IN A LIQUID ENVIRONMENT: (A) 3D MODELLING DESIGN AND (B) MANUFACTURED LABORATORY PROTOTYPE, WITHOUT THE UPPER CONTACT BODY

ONGOING RESEARCH PROJECTS

Some research projects are currently being developed at the University of Minho, which directly implies with the use of the FRICTORQ testing apparatus, in order to predict sensory comfort and touch provided by the fabrics used in each study. The next topics will review some of the results obtained so far in three of these ongoing projects, which are being undertaking by MSc researchers in the area of Biomedical Engineering, the first two projects, and Mechanical Engineering, the last.

Objective and Subjective Touch Evaluation of Hospital Clothing for Surgical Gowns

The aim is to study and characterize the sensory comfort and touch, as well as the requirements of the fabrics used in hospital garments, specifically in surgical gowns.

Comfort or discomfort sensations are to be studied and evaluated, with a special relevance on the sensory comfort of touch that the surgeons and other hospital technicians "*feel*" when using surgical gowns, knowing that these garments should provide protection from contamination by infectious agents such as viruses.

Two types of non-wovens were used:

- SMS (Spunbond-Melblown-Spunbond), consisting of 100% of polypropylene, and
- Suprel (S), made of 80% of polyethylene and 20% of polyester.

The obtained results using the FRICTORQ II model, for the mentioned non-wovens, are displayed in Figure 9. It can be observed that the friction coefficient of SMS, on both sides (inner face, IF, and outer face, OF), is higher than the Suprel non-woven. This finding can also be assessed in Table 1, where the mean values vary between 0,139 and 0,190, with the minimum value obtained for the S_OF sample and the maximum for the SMS_IF.

For comparing the obtained results a Scheffe analysis was computed to determine the existence of homogeneous subsets. Means for groups in homogeneous subsets are displayed in Table 2, using a harmonic mean sample size of 13. This analysis resulted in four different subsets. The multiple comparisons table was carefully examined and Table 3 was built presenting only the mean difference significance of the ANOVA comparison. It must be noticed that, statistically, all samples presented a different behaviour.

From all the collected results it was possible to confirm that the non-woven more rough to the touch (usually evaluated by sliding the fabric between the fingers) has a higher coefficient of friction. Between the two tested non-wovens, SMS is rougher than the Suprel, which confirms the previous plotted results.

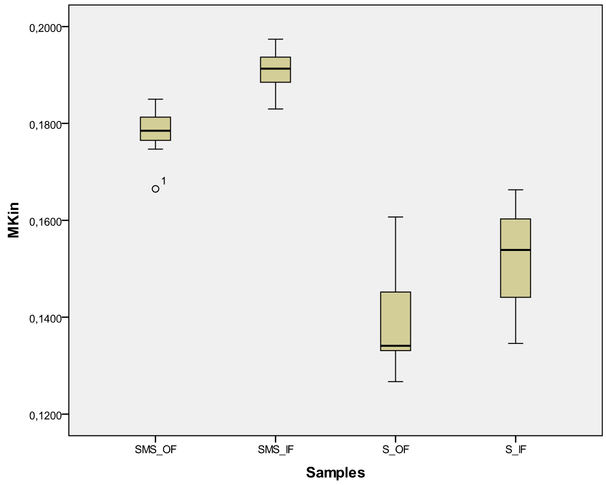


FIGURE 9
BOX-PLOT OF THE FRICTION COEFFICIENT OBTAINED FOR THE SMS AND SUPREL TESTED MATERIALS. (IF – INNER FACE, AND OF – OUTER FACE)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
SMS_OF	13	0,178	0,0046994	0,0013034	0,176	0,181	0,167	0,185
SMS_IF	13	**0,190**	0,0047811	0,0013260	0,187	0,193	0,183	0,197
S_OF	13	**0,139**	0,0103923	0,0028823	0,133	0,145	0,127	0,161
S_IF	13	0,153	0,0097636	0,0027079	0,147	0,159	0,135	0,166
Total	52	0,165	0,0218871	0,0030352	0,159	0,171	0,127	0,197

TABLE 1
SUMMARY OF THE STATISTICAL ANALYSIS OF THE RESULTS PRESENTED IN THE BOX-PLOT OF FIGURE 9

Samples	N	Subset for alpha = 0,05			
		1	2	3	4
SMS_OF	13	0,139			
SMS_IF	13		1,527		
S_OF	13			0,179	
S_IF	13				0,190
Significance		1,000	1,000	1,000	1,000

TABLE 2
SCHEFFE ANALYSIS FOR THE FRICTION COEFFICIENT

Samples	SMS_OF	SMS_IF	S_OF	S_IF
SMS_OF				
SMS_IF	0,0118*			
S_OF	0,0395*	0,0513*		
S_IF	0,0258*	0,0376*	0,0137*	

(*) The mean difference was significant at the 0,05 level.

TABLE 3
MEAN DIFFERENCE SIGNIFICANCE OF THE ANOVA COMPARISON

Objective and Subjective Touch Evaluation of Hospital and Surgical Covers

This research aimed at the evaluation of the parameters related with the touch of fabrics used in surgical covers and blankets. Different phases of the project included the acquaintance with the materials used in this field, the identification of the most relevant properties needed for the design of a surgical cover, the understanding of the importance of touch in the evaluation of the materials used in this study, the preparation of questionnaires to enable a preliminary subjective evaluation of touch, the comparison of the different materials used and the correlation with the objective and subjective parameters of touch.

For this purpose, FRICTORQ was one of the used instruments and five different materials (widely used in Portugal) were tested:

- Spunlace (FCP), made up of 55% cellulose and 45% polyester;

- VPE (viscose 48,3% , polyethylene 48,3% and 3,4% of hotmelt glue) and PEPP (polyethylene 38,9%, polypropylene 57,8% and 3,3% of hotmelt glue), and
- SMS and Suprel as before.

The obtained results are plotted on Figure 10. (Descriptive statistics and other data analysis are not reported for this study, although the same calculations as presented in the previous section were also computed.) According to these results it is possible to observe that Suprel is the material that exhibits a lower friction coefficient and the OF of VPE exhibits the higher coefficient of friction. Nevertheless FCP, SMS and PEPP show similar friction behaviour in both faces.

Although the correlation of the objective with the subjective parameters of touch for all these fabrics is not yet attained, as in the previous research project, the study and evaluation of the touch of materials used as protective barriers against contaminations is of great importance, particularly regarding the assessment of the comfort provided by the use of surgical clothing and covers made of such materials.

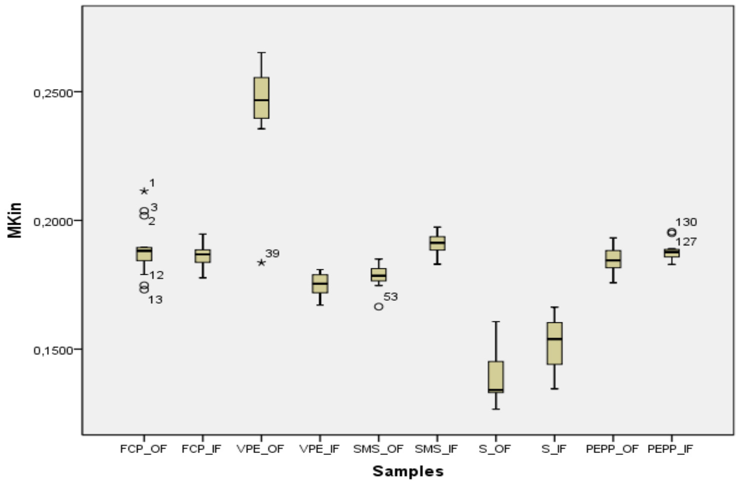


FIGURE 10

BOX-PLOT OF THE FRICTION COEFFICIENT OBTAINED FOR THE FCP, VPE, PEPP, SMS AND S TESTED MATERIALS. (IF – INNER FACE, AND OF – OUTER FACE)

Design and Development of an Add-on Kit Function to Measure Fabric Friction in a Liquid Environment

This project enabled the design, development and construction of the new add-on kit function already presented in Figure 8. A brief overview of the design process undertaken for this development can be obtained in [19]. Systematic tests are to be carried out to evaluate the efficiency of this new FRICTORQ function and two different swimwear knitted fabrics have also been selected. Not only the touch of the fabrics will be important at this stage, but also the study, evaluation and correlation of the fabrics surface characteristics with the water flow over the swimmers body, which is particularly important in sports competitions.

SKILLS ACQUIRED

The latter three projects, as mentioned before, are currently being undertaken by MSc students at the University of Minho (in the Textile Physics Laboratory). The skills acquired by these students can be summarized as follows:

- Expertise with tools, techniques, procedures and laboratory protocols, namely using KES instruments and tests, FRICTORQ and the thermal instrument ALAMBETA VŠST ÚZCHV;
- Ability to carried out the characterization of textile materials properties, in terms of friction, surface roughness, absortivity and thermal properties, sample thickness and other mechanical properties;
- Knowledge of engineering design methods, statistical tools for data processing and analysis (regarding the software SPSS® Statistics V.18.0), CAD and Fluent software;
- Autonomy to use, within each area of research, the background knowledge acquired during their undergraduate courses, and;
- Participation in R&D projects and in activities of research and resources management.

CONCLUDING REMARKS

This paper reviewed the design and development of a laboratory testing apparatus for measuring the friction coefficient in textiles and other 2D soft structures named FRICTORQ. All the designs developed so far have been presented, as part of a research work that gathers the Departments of Mechanical and Textile Engineering of the University of Minho.

The research framework of three MSc students have also been reported, which represents a further step to accomplish the final overall objective: "*the development of a friction testing apparatus to enable a quantitative assessment of the touch/handle, in order to predict the comfort behaviour of 2D structures when used or touched by humans*". The integration of knowledge, skills and performance relating to Competency-Based Education [20], [21] in the field of Mechanical Engineering Design and Characterization of new Materials and Products, to be in contact with liquid environments and for hospital applications, was implemented based on the reported projects. The role of the supervisors along this process was just to coach and support students in practice, allowing them, nevertheless, the ability to perform particular scientific activities without any direct supervision.

Future work for any of these individual projects will be focused on establishing the correlations between friction (and other important properties) with touch, as well as on the completeness and analysis of the questionnaires filled by the numerous hospital technicians contacted.

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