Strategic Selection of Metallic Alloys: AHP Evaluation of Seven 3D Printing Filaments for Critical Underwater Human-Machine Interface Components.

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Abstract - Metallic additive manufacturing, or metal 3D printing, has evolved into a fundamental pillar of modern industry, enabling the production of complex geometries that are not possible with traditional methods. Adopting this technology is a strategic decision that requires a detailed analysis of the material, the printing technology, and the associated costs. This report presents an exhaustive analysis of seven of the most relevant metallic filaments and powders in the industry. Their physical and mechanical properties, the required printing technologies, their distinctive advantages, and their most appropriate applications are examined. The analysis reveals that material selection is a strategic determination that defines the market niche, the performance of the part, and the economic viability of the project.

Keywords - Multi-criteria analysis, Analytic Hierarchy Process, Moora, Vikor, Metal 3D printing, Metallic filaments, Additive manufacturing, Underwater Components, Decision Support System.

I. INTRODUCTION

Metallic additive manufacturing, or metal 3D printing, has transitioned from a prototyping technology to a key pillar of the Fourth Industrial Revolution [4]. Unlike traditional subtractive manufacturing methods, this technology builds parts layer by layer, enabling the creation of intricate geometries, lightweight structures, and organic shapes impossible to achieve otherwise [1]. This approach has catalyzed significant innovations in sectors operating in harsh environments and with critical technological components, such as medicine, energy, and human-machine interfaces (HMI), where performance optimization is essential [18, 21, 23].

The versatility of metallic additive manufacturing manifests on multiple fronts. Firstly, it facilitates the consolidation of multiple components into a single part. This process not only simplifies assemblies and reduces supply chain complexity but also increases the structural integrity and reliability of the final product. An integrated component is inherently stronger than one assembled from several parts [1, 6]. This versatility is critical for components intended for aquatic environments, where part consolidation enhances integrity against pressure and weight reduction improves the efficiency of underwater vehicles and robotic systems. Secondly, its ability to reduce the weight of structures through topological optimization and the use of internal lattice structures is a critical advancement in industries such as aerospace and automotive [1].

This allows engineers to design parts with optimized material distribution, placing mass only where it is needed for structural support, which translates directly into greater efficiency and fuel savings. These advancements have positioned 3D printing as a disruptive force with the capacity to radically transform the paradigms of design, production, and the value chain across a wide range of sectors [6].

The adoption of metallic additive manufacturing represents a strategic decision that goes far beyond the mere acquisition of a machine. It involves a detailed analysis of multiple variables, including material selection, printing technology, total cost of ownership, and post-processing requirements [6, 7]. Each metallic material, whether it be Stainless Steel 316L, Titanium 64, or Inconel 718, has a unique set of mechanical properties, processing requirements, and varying costs [10, 18, 21]. This diversity demands a structured and rigorous approach to decision-making, especially when the failure of a component can compromise a critical mission or operator safety. This is where multi-criteria analysis tools, such as the Analytic Hierarchy Process (AHP), demonstrate their value by allowing for a systematic evaluation of multiple factors, both quantitative and qualitative, to determine the best alternative. The cost of machinery, for example, can vary drastically, with powder bed laser fusion systems requiring an initial investment of hundreds of thousands of dollars, while emerging technologies like filament extrusion are more accessible [6, 7].

The correct choice of material and technology is vital for project success. A material with high corrosion resistance, such as Stainless Steel 316L, is ideal for components exposed to saline and underwater environments [9], while Tool Steel H13 is unsurpassed in applications requiring extreme hardness and abrasion resistance [13, 14]. On the other hand, the high corrosion resistance, fatigue strength, and strength-to-weight ratio of Titanium 64 make it indispensable for structural components subjected to high pressures [21]. Inconel 718, a superalloy, is the only viable option for parts that require superior resistance to corrosion on the seabed and high structural strength [18]. A deep understanding of these properties is crucial, as an incorrectly selected material could not only lead to performance failure but also generate an unsustainable over-cost.

This report presents an exhaustive and comparative analysis of seven of the most relevant metallic filaments and powders in the 3D printing industry: Stainless Steel 316L, Stainless Steel 17-4 PH, Tool Steel H13, Cast Aluminum (AlSi10Mg), Titanium 64 (Ti6Al4V), Inconel 718, and Cobalt-Chrome. The objective is to provide a clear and well-founded guide for the strategic selection of materials intended for critical components of underwater human-machine interfaces. To this end, their key physical and mechanical properties, the printing technologies required for each, their distinctive advantages, and their most appropriate applications are examined. Through this document, we seek to offer a supporting tool that simplifies the decision-making process and ensures that the chosen material is the optimal one for the specific requirements of each application. Metallic additive manufacturing is not just a new way of making things—it is a new way of thinking about design, production, and material potential.

II. BACKGROUND ON THE USE OF MCDM FOR THE PROPOSED TOPIC

Multi-Criteria Decision-Making (MCDM) is a branch of operational research that focuses on evaluating multiple, often conflicting, criteria to arrive at an optimal decision [30]. This approach is especially relevant in engineering and science problems where the ideal solution must satisfy a variety of requirements. In the context of metallic additive manufacturing, material selection is, by nature, a multi-criteria problem. The choice of a filament or powder is not based solely on its cost but must also consider crucial mechanical properties, processing factors, and associated costs [30, 31].

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty, is a widely recognized and applied MCDM method for addressing these problems in a structured and systematic manner. AHP decomposes a complex decision into a hierarchy of criteria and alternatives, allowing the decision-maker to make pairwise comparative judgments to determine the relative importance of each factor [31, 32].

The usefulness of AHP is demonstrated in the resolution of everyday and complex problems. For example, in choosing consumer goods, such as a family car, AHP can be used to weight criteria such as maintenance cost, safety, and style, allowing for a rational and transparent decision [32]. This same methodological framework is directly applicable to material selection in additive manufacturing. The main advantage of AHP lies in its ability to transform subjective judgments and qualitative data into concrete numerical values. This quantification process ensures that the final decision is rational and well-founded.

In the field of metallic filaments, AHP allows engineers to balance performance, cost, and process feasibility. For instance, even though Titanium 64 offers an excellent strength-to-weight ratio, its high cost and processing requirements may limit its use in non-critical applications. Thus, the application of AHP in this study offers a robust and objective method for evaluating the seven materials, transforming qualitative judgments into a weighting of key criteria (such as biocompatibility or temperature resistance), thereby ensuring that the final material selection is logical, transparent, and aligned with the specific needs of each project [31, 32].

III. PROPOSED TECHNIQUE

The evaluation proposal is based on the Analytic Hierarchy Process (AHP) to systematically weigh the multiple factors that define the feasibility and performance of materials in a high-criticality environment, such as the underwater one.

The evaluation is based on twelve essential criteria, derived from the extreme requirements imposed by Underwater Human-Machine Interfaces (HMI): high pressure, constant exposure to saltwater (corrosion), and the need for absolute structural reliability. These criteria are:

1. Corrosion Resistance: The material's ability to resist degradation caused by exposure to an environment.
2. High Temperature Resistance: The capacity to maintain strength and structural integrity under conditions of extreme heat.
3. Wear/Abrasion Resistance: The material's surface hardness and its ability to resist wear.
4. Biocompatibility: The material's capacity to interact with biological systems without causing adverse effects.
5. Cost per Kg: The price of the metallic filament or powder, a crucial economic factor.
6. Market Availability: The ease of finding the material for acquisition and use.
7. Machinery Cost: The initial investment required for the 3D printer to process the material.
8. Post-Processing Cost: The costs and complexity associated with finishing and treating the printed part.
9. Ultimate Tensile Strength (UTS): The maximum stress the material can withstand while being stretched before failing.
10. Density: The mass per unit volume of the material.
11. 3D Printing Processability: The ease with which the material can be printed, considering factors such as temperature control and process stability.
12. Hardness: The resistance of a material to localized plastic deformation, measured on a scale such as Rockwell HRC.

Material Profiles and Visualization

For a deeper understanding of each alternative, detailed profiles of the filaments are presented below, including a representative image.

- Stainless Steel 17-4 PH

This is a martensitic stainless steel alloy (they basically have a metallographic structure formed by martensite) valued for its high strength and excellent hardness, comparable to tool steels. It's widely used in applications that require a combination of high strength and corrosion resistance, such as the aerospace and defense industries. It is available in powder or filament form to be processed by powder bed fusion technologies [11, 12].

Figure 1: Stainless Steel 17-4 PH

- Stainless Steel 316L

Known as the "marine grade stainless steel," 316L is an alloy that stands out for its superior corrosion resistance, especially in saline and acidic environments. Its primary advantage is its biocompatibility, which makes it ideal for the manufacturing of surgical instruments and medical implants. It is also widely used in the food processing and chemical industries [9, 10].

Figure 2: Stainless Steel 316L

- Tool Steel H13

This material is an alloy of chromium, molybdenum, and vanadium, engineered for extreme resistance to thermal fatigue and high hardness. It is the primary choice for tools operating at high temperatures, such as dies for die casting, injection molds, and forging dies. Its high hardness and abrasion resistance make it a high-performance material in demanding industrial applications [13-15].

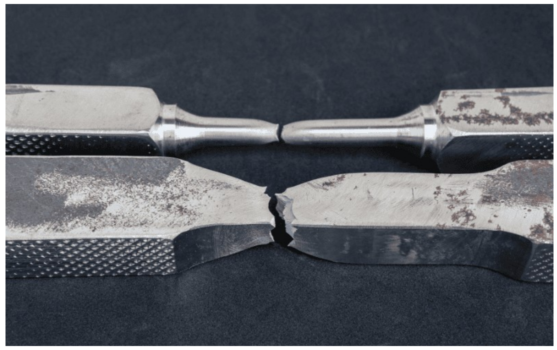

Figure 3: Tool Steel H13

- Cast Aluminum (AlSi10Mg)

AlSi10Mg is an aluminum alloy with silicon and magnesium, optimized for 3D printing. Its main advantage is its excellent strength-to-weight ratio, which makes it ideal for the aerospace, automotive, and robotics industries. Unlike other metals, aluminum parts are considerably lighter, although their processability can be complex [2, 17].

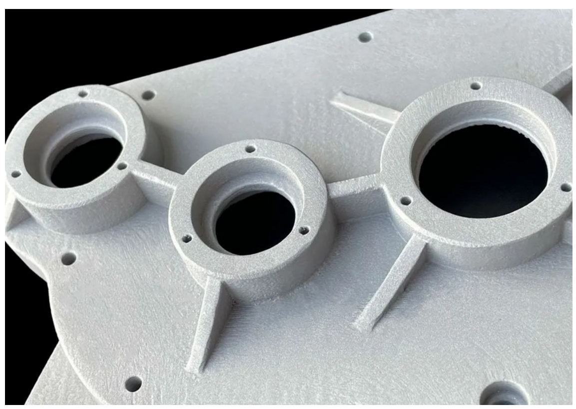

Figure 4: Cast Aluminum

- Titanium 64 (Ti6Al4V)

Titanium 64 is one of the most important alloys in additive manufacturing. It is recognized for its extraordinary strength-to-weight ratio, its excellent corrosion resistance, and, most importantly, its high biocompatibility. It is the material of choice (the reference material) for the aerospace industry, where weight reduction is critical, and for the manufacturing of medical implants, prostheses, and orthopedic devices [21, 22].

Figure 5: Titanium 64

- Inconel 718

Known as a "superalloy," Inconel 718 is a nickel-chromium alloy that maintains high strength and ductility at extremely high temperatures. Its corrosion resistance and mechanical performance in severe environments make it indispensable in the aerospace industry, especially for the manufacturing of rocket engine components, gas turbines, and turbochargers [18-20].

Figure 6: Iconel 718

- Cobalt-Chrome

Cobalt-chrome alloys are known for their exceptional wear resistance, high corrosion resistance, and, like titanium, their biocompatibility. They are primarily used in the medical industry for dental implants and orthopedic prostheses, as well as in high-performance applications in the aerospace and turbine industries [23, 25, 29].

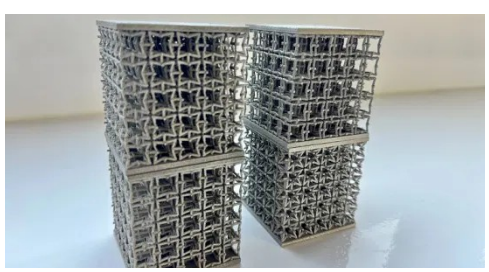

Figure 7: Cobalt Chrome

IV. PROBLEM DESCRIPTION

Metallic additive manufacturing, while offering unprecedented design freedom, faces an exponentially more complex selection challenge when applied to critical Human-Machine Interface (HMI) components intended for underwater environments. In this context, a material failure not only entails an economic loss but can compromise the mission, equipment functionality, and even human safety [6, 7].

The central problem is no longer merely economic but one of survival and structural reliability under extreme conditions. The simplistic choice of a material based solely on cost per kilogram is, in this domain, an engineering irresponsibility that can lead to catastrophic failures [7, 8].

The Underwater Triple Threat: Pressure, Corrosion, and Fatigue

Underwater HMI components (such as sensor housings, robotic gripping mechanisms, or autonomous vehicle elements) operate under a triad of destructive forces that drastically limit material selection:

Accelerated Marine Corrosion: Seawater, rich in chlorides, is an aggressive electrolyte. While alloys like Stainless Steel 316L offer good resistance, the granular microstructure inherent to 3D-printed parts (especially those made by powder bed fusion) can make them susceptible to pitting corrosion and galvanic corrosion, as reported by studies in marine environments [33].

High Pressures and Cyclic Pressure Fatigue: Repeated submersion and ascent subject components to cycles of compression and decompression loading. The Ultimate Tensile Strength (UTS) and Fatigue Resistance must be exceptionally high to prevent failure by collapse or by microscopic cracks generated by fatigue [35].

Corrosion-Fatigue: The interaction of the corrosive medium with mechanical fatigue stresses is the most dangerous scenario. Corrosion weakens the surface, and cyclic stress exploits that weakness to propagate cracks. This phenomenon drastically reduces the fatigue limit of alloys, including Titanium 64 (Ti6Al4V), despite its reputation for corrosion resistance [34, 35].

Technological and Economic Challenge of High Reliability

The viability of a 3D printing project for critical components depends on the synergy among the material, the processing technology, and the total cost of ownership.

Dependence on High-Investment Technologies: The high-performance metals required for underwater applications (such as Titanium 64, Inconel 718, and Cobalt-Chrome) only achieve their optimal structural reliability and corrosion resistance when processed by advanced technologies like Laser Powder Bed Fusion (LPBF/DMLS) [27, 28]. These printing systems, which use inert gases and high-power lasers, require an initial investment exceeding hundreds of thousands of dollars, significantly raising the project's barrier to entry [6, 7].

Hidden Impact of Post-Processing: Even more accessible technologies using bound filaments require intensive thermal post-processing to achieve the final density and mechanical properties needed to withstand pressure. This process, which adds a layer of complexity, cost, and time, cannot be underestimated [3, 16].

The Complexity of Total Cost of Ownership: The TCO of a part goes beyond the cost per kilogram of filament. It is the sum of the material, machinery depreciation, energy consumption, printing time, and, critically, the expensive finishing treatments (machining, polishing, etc.) that ensure surface integrity and the release of internal stresses, which are vital for preventing fatigue failure [6, 7]. A simple comparison of filament prices is misleading and underestimates the true investment required [8].

The need for a material that balances the structural strength of Titanium 64 with the economic viability of a Stainless Steel, and which can resist corrosion-fatigue, necessitates a rigorous multi-criteria evaluation. The lack of a clear decision framework that simultaneously weighs all these factors can lead to the selection of suboptimal materials, risking the final application.

V. METHODOLOGY, ANALYSIS, AND RESULTS

Results Based on the Analytic Hierarchy Process (AHP)

Criteria	3D Printing Filaments for Critical Underwater Human-Machine Interface Components							
	Stainless Steel 17-4 PH	Stainless Steel 316L	Tool Steel H13	Cast Aluminum (AlSi10Mg)	Titanium 64 (Ti6Al4V)	Inconel 718	Cobalt-Chrome	Measure Unit
Corrosion Resistance	4.103	7	1	1.413	6.172	6.793	6.379	Likert
High Temperature Resistance	3.307	3.307	6.692	1	5.615	7	5.923	Likert
Wear/Abrasion Resistance	3.647	2.764	7	1	5.411	6.647	6.294	Likert
Biocompatibility	5.666	6.333	1	1.666	7	3.666	6.066	Likert
Cost per Kg	5.021	5.851	4.51	7	2.595	1	3.553	Likert
Market Availability	5.736	7	4.947	1	4.157	5.421	3.368	Likert
Machinery Cost	5.552	7	4.212	3.461	2.593	1.627	1	Likert
Post-Processing Cost	4.374	5.517	2.531	7	4.381	1	2.512	Likert
Ultimate Tensile Strength (UTS)	4.577	2.633	7	1	4.324	5.666	4.111	Likert
Density	6.357	6.678	6.464	1	2.842	6.892	7	Likert
3D Printing Processability	6.251	7	4.112	1	4.752	3.254	3.716	Likert
Hardness	5.042	2.894	7	1	4.601	5.421	5.736	Likert

Figure 8: Table of Normalized Initial Values on the Likert Scale

The Table of Normalized Initial Values on the Lickert Scale was used as a reference, which quantifies the evaluation of each alternative with respect to its respective criteria. This rating scale assigns values in a range from 1 to 7, where a score of 7 represents the most desirable (optimal) performance on the evaluated criterion, and 1 indicates the worst performance.

Subsequently, a hierarchy of criteria was established by grouping the twelve evaluation factors into four main categories (higher-level criteria). These main criteria are: Performance, Physical Properties, Viability, and Cost. The detailed composition of each group is presented in the following table:

Criteria and sub-criteria			
Performance (C1)	Physical Properties (C2)	Viability (C3)	Costs (C4)
Corrosion Resistance (C1.1)	Density (C2.1)	3D Printing Processability (C3.1)	Cost per Kg (C4.1)
High Temperature Resistance (C1.2)	Biocompatibility (C2.2)	Market Availability (C3.2)	Machinery Cost (C4.2)
Wear/Abrasion Resistance (C1.3)	Hardness (C2.3)		Post-Processing Cost (C4.3)
Ultimate Tensile Strength (UTS) (C1.4)			

Figure 9: Table of Criteria Hierarchy

Once the criteria categories were defined, the next step was to determine the relative importance weighting of each group for the final decision. For this purpose, the AHP pairwise comparison method was applied, using Saaty's Fundamental Scale. This scale, which ranges from 1 to 9, allows for the quantification of preference or importance when confronting two elements, where 1 indicates equal importance and 9 signifies that one element is extremely more important than the other. Based on these judgments, the following tables were constructed to establish the relative importance of each category.

General Criteria						
	C1	C2	C3	C4	Sums	Proper Vector
C1	1.00	5.00	5.00	3.00	14.0000	0.5303
C2	0.20	1.00	1.00	0.33	2.5333	0.0960
C3	0.20	1.00	1.00	0.33	2.5333	0.0960
C4	0.33	3.00	3.00	1.00	7.3333	0.2778
				Totals	26.4000	1.0000

Figure 10: Pairwise table of the four main categories

In this table, it is observed that the category with the highest importance weighting is Performance, followed by the Cost category. Finally, the Physical Properties and Viability categories share the same level of relative importance.

For the continuation of the analysis, the next step was to determine the individual relative importance of the twelve evaluation criteria within their higher-level category. This process was achieved by repeating the AHP pairwise comparisons, applying the method separately to the criteria grouped under each of the four main categories.

Performance Criteria							
	C1.1	C1.2	C1.3	C1.4	Sums	Proper Vector	Resultant Vector
C1.1	1.00	7.00	3.00	3.00	14.0000	0.4634	0.2458
C1.2	0.14	1.00	0.20	0.20	1.5429	0.0511	0.0271
C1.3	0.33	5.00	1.00	1.00	7.3333	0.2427	0.1287
C1.4	0.33	5.00	1.00	1.00	7.3333	0.2427	0.1287
				Totals	30.2095	1.0000	0.5303

Figure 11: Criteria Prioritization Matrix within the Performance Category

In this table, it is observed that criterion C1.1 (Corrosion Resistance) is the most important within its category, obtaining the highest weighting. This result is consistent with the objective of the study, given that corrosion resistance is a critically important factor for the final decision-making in an underwater environment.

Physical Properties Criteria						
	C2.1	C2.2	C2.3	Sums	Proper Vector	Resultant Vector
C2.1	1.00	0.33	3.00	4.3333	0.2915	0.0280
C2.2	3.00	1.00	5.00	9.0000	0.6054	0.0581
C2.3	0.33	0.20	1.00	1.5333	0.1031	0.0099
			Totals	14.8667	1.0000	0.0960

Figure 12: Criteria Prioritization Matrix within the Physical Properties Criteria

In the Physical Properties category, the table analysis reveals that criterion C2.2 (Biocompatibility) is the most prominent factor, obtaining the highest importance weighting.

Viability Criteria					
	C3.1	C3.2	Sums	Proper Vector	Resultant Vector
C3.1	1.00	5.00	6	0.8333	0.0800
C3.2	0.20	1.00	1.2	0.1667	0.0160
		Totals	7.2	1.0000	0.0960

Figure 13: Criteria Prioritization Matrix within the Viability Criteria

In the Viability criteria table, a clear distinction of importance is observed in favor of factor C3.1 (3D Printing Processability), which stands out with a significantly higher weighting than criterion C3.2 (Market Availability).

Cost Criteria						
	C4.1	C4.2	C4.3	Sums	Proper Vector	Resultant Vector
C4.1	1.00	0.20	0.33	1.5333	0.1031	0.0286
C4.2	5.00	1.00	3.00	9.0000	0.6054	0.1682
C4.3	3.00	0.33	1.00	4.3333	0.2915	0.0810
			Totals	14.8667	1.0000	0.2778

Figure 14: Criteria Prioritization Matrix within the Cost Criteria

In the Cost criteria table, the analysis reveals that Machinery Cost stands out as the most important factor. This result is logically consistent, since machinery cost represents the most significant initial investment and the main barrier to entry for metallic 3D printing technology. In contrast, the Cost per Kilogram (Cost per Kg) of the material is weighted with lower importance, given that it is a recurring operational expense which, although relevant, is more prone to market variations or to being distributed throughout the project's life cycle.

After performing the pairwise comparisons at all levels, from the main categories to the individual criteria, the next critical step in the AHP process is the synthesis of these judgments to obtain the global weighting of each element in the hierarchy. This procedure integrates the local priorities of the sub-criteria with the weightings of their respective main categories by multiplying their values. The result of this synthesis is the construction of the complete hierarchy diagram, as shown, where each box exhibits its global weight or relative importance with respect to the overall objective of selecting the best filament for underwater conditions. These global weights are fundamental, as they reflect the final influence of each factor in the subsequent phase of alternative evaluation.

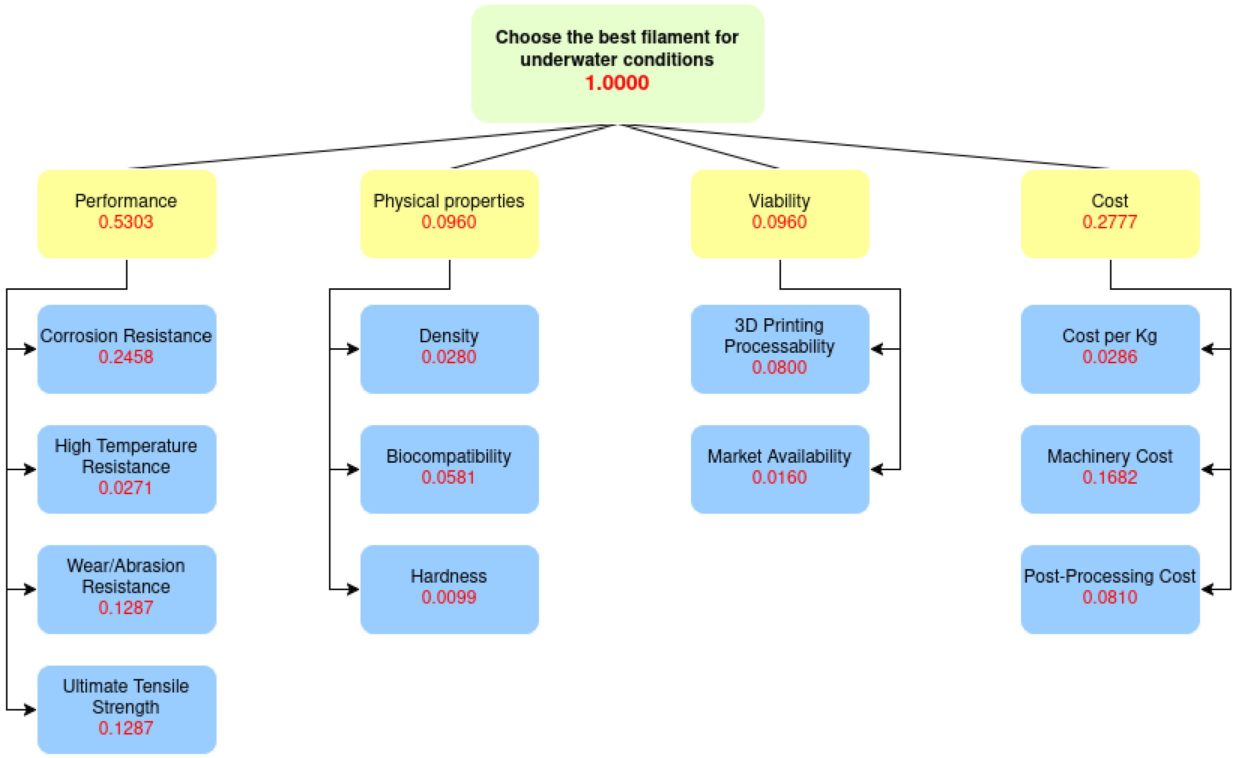

Figure 15: Hierarchy Diagram of Each Criterion and Sub-criterion with its Respective Weighting

Once the global weightings of the criteria were established, the analysis proceeds to evaluate the seven available material alternatives. To achieve this, the pairwise comparison process is repeated, applying the method to the alternatives with respect to each of the twelve criteria individually.

Alternative	Metallic Filament
A1	Stainless Steel 17-4 PH
A2	Stainless Steel 316L
A3	Tool Steel H13
A4	Cast Aluminum (AlSi10Mg)
A5	Titanium 64 (Ti6Al4V)
A6	Inconel 718
A7	Cobalt-Chrome

Figure 16: Table of Variable Assignment for Each Alternative

Before proceeding with the rigorous pairwise comparison process to evaluate the alternatives, it was essential to code each of the seven material options.

Specifically, the adjacent table establishes the correspondence: A1 represents the material Stainless Steel 17-4 PH, A2 corresponds to Stainless Steel 316L, and the process continues sequentially with the others. The purpose of this standardization is to facilitate and simplify the data entry into the 7x7 comparison matrices and the subsequent management of the weightings. This makes the process of calculating the local priority vectors for each criterion more agile and less prone to material identification errors.

Corrosion Resistance Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	0.2000	5.0000	3.0000	0.3333	0.3333	0.3333	10.2000	0.0987	0.0243
A2	5.0000	1.0000	9.0000	7.0000	3.0000	3.0000	3.0000	31.0000	0.3000	0.0737
A3	0.2000	0.1111	1.0000	0.3333	0.1429	0.1429	0.1429	2.0730	0.0201	0.0049
A4	0.3333	0.1429	3.0000	1.0000	0.2000	0.2000	0.2000	5.0762	0.0491	0.0121
A5	3.0000	0.3333	7.0000	5.0000	1.0000	1.0000	1.0000	18.3333	0.1774	0.0436
A6	3.0000	0.3333	7.0000	5.0000	1.0000	1.0000	1.0000	18.3333	0.1774	0.0436
A7	3.0000	0.3333	7.0000	5.0000	1.0000	1.0000	1.0000	18.3333	0.1774	0.0436
							Total	103.3492	1.0000	0.2458

Figure 17: Table of alternatives pairwise comparison for Corrosive Resistance Criteria

The analysis of the pairwise comparison matrix for the Corrosion Resistance criterion (C1.1) indicates that the Stainless Steel 316L (A2) alternative presents the highest local priority. It is followed in order of importance by Titanium 64 (Ti6Al4V) (A5), Inconel 718 (A6), and Cobalt-Chrome (A7).

High Temperature Resistance Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	0.1429	3.0000	0.2000	0.1429	0.2000	5.6857	0.0509	0.0014
A2	1.0000	1.0000	0.1429	3.0000	0.2000	0.1429	0.2000	5.6857	0.0509	0.0014
A3	7.0000	7.0000	1.0000	9.0000	3.0000	1.0000	3.0000	31.0000	0.2774	0.0075
A4	0.3333	0.3333	0.1111	1.0000	0.1429	0.1111	0.1429	2.1746	0.0195	0.0005
A5	5.0000	5.0000	0.3333	0.1429	1.0000	0.2000	1.0000	12.6762	0.1134	0.0031
A6	7.0000	7.0000	1.0000	9.0000	5.0000	1.0000	5.0000	35.0000	0.3132	0.0085
A7	5.0000	5.0000	0.3333	7.0000	1.0000	0.2000	1.0000	19.5333	0.1748	0.0047
							Total	111.7556	1.0000	0.0271

Figure 18: Table of alternatives pairwise comparison for High Temperature Resistance Criteria

Corresponding to this comparison, the High-Temperature Resistance criterion indicates that the Inconel 718 (A6) alternative presents the highest local priority. This is followed by Tool Steel H13 (A3) and Cobalt-Chrome (A7). The alternatives Stainless Steel 17-4 PH (A1) and Stainless Steel 316L (A2) share the lowest priority.

Wear/Abrasion Resistance Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	0.2000	3.0000	0.3333	0.2000	0.2000	5.9333	0.0575	0.0074
A2	1.0000	1.0000	0.1429	3.0000	0.2000	0.2000	0.2000	5.7429	0.0557	0.0072
A3	5.0000	7.0000	1.0000	9.0000	3.0000	1.0000	1.0000	27.0000	0.2617	0.0337
A4	0.3333	0.3333	0.1111	1.0000	0.1429	0.1111	0.1429	2.1746	0.0211	0.0027
A5	3.0000	5.0000	0.3333	7.0000	1.0000	1.0000	1.0000	18.3333	0.1777	0.0229
A6	5.0000	5.0000	1.0000	9.0000	1.0000	1.0000	1.0000	23.0000	0.2229	0.0287
A7	5.0000	5.0000	1.0000	7.0000	1.0000	1.0000	1.0000	21.0000	0.2035	0.0262
							Total	103.1841	1.0000	0.1287

Figure 19: Table of alternatives pairwise comparison for Wear/Abrasion Resistance Criteria

The analysis of the pairwise comparison matrix for the Wear/Abrasion Resistance criterion indicates that the Tool Steel H13 (A3) alternative is positioned as having the highest local priority in this category. This result is followed by Inconel 718 (A6) and Cobalt-Chrome (A7), a ranking that reinforces the recognition of Tool Steel H13's superior wear resistance in demanding applications.

Ultimate Tensile Strength (UTS) Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	3.0000	0.2000	5.0000	1.0000	0.3333	1.0000	11.5333	0.1160	0.0149
A2	0.3333	1.0000	0.1429	3.0000	0.3333	0.2000	0.3333	5.3429	0.0537	0.0069
A3	5.0000	7.0000	1.0000	9.0000	5.0000	3.0000	5.0000	35.0000	0.3519	0.0453
A4	0.2000	0.3333	0.1111	1.0000	0.2000	0.1429	0.2000	2.1873	0.0220	0.0028
A5	1.0000	3.0000	0.2000	5.0000	1.0000	0.3333	1.0000	11.5333	0.1160	0.0149
A6	3.0000	5.0000	0.3333	7.0000	3.0000	1.0000	3.0000	22.3333	0.2245	0.0289
A7	1.0000	3.0000	0.2000	5.0000	1.0000	0.3333	1.0000	11.5333	0.1160	0.0149
							Total	99.4635	1.0000	0.1287

Figure 20: Table of alternatives pairwise comparison for Ultimate Tensile Strength Criteria

Regarding the Ultimate Tensile Strength (UTS) criterion, the Tool Steel H13 (A3) alternative is established as having the maximum local priority in the pairwise comparison matrix. It is followed in importance by Inconel 718 (A6). Finally, the Stainless Steel 17-4 PH (A1), Titanium 64 (Ti6Al4V) (A5), and Cobalt-Chrome (A7) alternatives share the same priority level in this specific evaluation.

Density Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	1.0000	9.0000	5.0000	1.0000	1.0000	19.0000	0.1830	0.0051
A2	1.0000	1.0000	1.0000	9.0000	5.0000	1.0000	1.0000	19.0000	0.1830	0.0051
A3	1.0000	1.0000	1.0000	9.0000	5.0000	1.0000	1.0000	19.0000	0.1830	0.0051
A4	0.1111	0.1111	0.1111	1.0000	0.3333	0.1111	0.1111	1.8889	0.0182	0.0005
A5	0.2000	0.2000	0.2000	3.0000	1.0000	0.2000	0.1429	4.9429	0.0476	0.0013
A6	1.0000	1.0000	1.0000	9.0000	5.0000	1.0000	1.0000	19.0000	0.1830	0.0051
A7	1.0000	1.0000	1.0000	9.0000	7.0000	1.0000	1.0000	21.0000	0.2023	0.0057
							Total	103.8317	1.0000	0.0280

Figure 21: Table of alternatives pairwise comparison for Density Criteria

In the Density criterion, the pairwise comparison assigns the maximum local priority to the Cobalt-Chrome (A7) alternative, slightly ahead of the others. It is important to note that the Stainless Steel 17-4 PH (A1), Stainless Steel 316L (A2), Tool Steel H13 (A3), and Inconel 718 (A6) alternatives share the same and high level of priority, which implies that for decision-making, these five options have an equally desirable density.

Biocompatibility Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	7.0000	5.0000	0.3333	3.0000	1.0000	18.3333	0.1811	0.0105
A2	1.0000	1.0000	7.0000	5.0000	1.0000	5.0000	1.0000	21.0000	0.2075	0.0121
A3	0.1429	0.1429	1.0000	1.0000	0.1111	0.3333	0.1429	2.8730	0.0284	0.0016
A4	0.2000	0.2000	1.0000	1.0000	0.1429	0.3333	0.2000	3.0762	0.0304	0.0018
A5	3.0000	1.0000	9.0000	7.0000	1.0000	5.0000	1.0000	27.0000	0.2668	0.0155
A6	0.3333	0.2000	3.0000	3.0000	0.2000	1.0000	0.2000	7.9333	0.0784	0.0046
A7	1.0000	1.0000	7.0000	5.0000	1.0000	5.0000	1.0000	21.0000	0.2075	0.0121
							Total	101.2159	1.0000	0.0581

Figure 22: Table of alternatives pairwise comparison for Biocompatibility Criteria

In the Biocompatibility criterion, the alternative that stands out with the highest local priority is Titanium 64 (Ti6Al4V) (A5), which is consistent with this material's reputation as the reference option for implants and medical devices. The Stainless Steel 316L (A2) and Cobalt-Chrome (A7) alternatives follow with the same and high level of priority, reflecting the suitability of these materials in biological applications.

Hardness Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	3.0000	0.3333	5.0000	1.0000	1`	1.0000	11.3333	0.1250	0.0012
A2	0.3333	1.0000	0.1429	3.0000	0.3333	0.3333	0.2000	5.3429	0.0589	0.0006
A3	3.0000	7.0000	1.0000	9.0000	5.0000	3.0000	3.0000	31.0000	0.3419	0.0034
A4	0.2000	0.3333	0.1111	1.0000	0.2000	0.1429	0.1429	2.1302	0.0235	0.0002
A5	1.0000	3.0000	0.2000	5.0000	1.0000	1`	1.0000	11.2000	0.1235	0.0012
A6	1.0000	3.0000	0.3333	7.0000	1.0000	1.0000	1.0000	14.3333	0.1581	0.0016
A7	1.0000	5.0000	0.3333	7.0000	1.0000	1`	1.0000	15.3333	0.1691	0.0017
							Total	90.6730	1.0000	0.0099

Figure 23: Table of alternatives pairwise comparison for Hardness Criteria

Based on the Hardness criterion, the pairwise comparison establishes the Tool Steel H13 (A3) alternative as having the maximum local priority. This result is congruent with the material's profile, which is designed to exhibit extreme hardness and abrasion resistance in demanding industrial applications. It is followed by the Cobalt-Chrome (A7) alternative and then Inconel 718 (A6), while Cast Aluminum (AlSi10Mg) (A4) obtains the lowest local priority in this criterion.

3D Printing Processability Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	3.0000	7.0000	3.0000	5.0000	3.0000	23.0000	0.2473	0.0198
A2	1.0000	1.0000	5.0000	9.0000	3.0000	5.0000	5.0000	29.0000	0.3119	0.0249
A3	0.3333	0.2000	1.0000	5.0000	1.0000	3.0000	1.0000	11.5333	0.1240	0.0099
A4	0.1429	0.1111	0.2000	1.0000	0.2000	0.3333	0.2000	2.1873	0.0235	0.0019
A5	0.3333	0.3333	1.0000	5.0000	1.0000	1.0000	0.3333	9.0000	0.0968	0.0077
A6	0.2000	0.2000	0.3333	3.0000	1.0000	1.0000	1.0000	6.7333	0.0724	0.0058
A7	0.3333	0.2000	1.0000	5.0000	3.0000	1.0000	1.0000	11.5333	0.1240	0.0099
							Total	92.9873	1.0000	0.0800

Figure 24: Table of alternatives pairwise comparison for 3D Printing Processability Criteria

According to the 3D Printing Processability criterion, the pairwise comparison indicates Stainless Steel 316L (A2) as the alternative with the maximum local priority. It is followed by Stainless Steel 17-4 PH (A1). The high prioritization of these stainless steels is consistent with their greater ease of processing in existing 3D printing technologies. In contrast, the Cast Aluminum (AlSi10Mg) (A4) and Inconel 718 (A6) alternatives are positioned with the lowest priority, reflecting the inherent complexity and high technical requirements for their additive processing.

Market Availability Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	0.3333	1.0000	7.0000	3.0000	1.0000	5.0000	18.3333	0.1831	0.0029
A2	3.0000	1.0000	3.0000	9.0000	5.0000	5.0000	7.0000	33.0000	0.3295	0.0053
A3	1.0000	0.3333	1.0000	7.0000	1.0000	1.0000	3.0000	14.3333	0.1431	0.0023
A4	0.1429	0.1111	0.1429	1.0000	0.2000	0.1429	0.3333	2.0730	0.0207	0.0003
A5	0.3333	0.2000	1.0000	5.0000	1.0000	0.3333	3.0000	10.8667	0.1085	0.0017
A6	1.0000	0.2000	1.0000	7.0000	3.0000	1.0000	3.0000	16.2000	0.1618	0.0026
A7	0.2000	0.1429	0.3333	3.0000	0.3333	0.3333	1.0000	5.3429	0.0533	0.0009
							Total	100.1492	1.0000	0.0160

Figure 25: Table of alternatives pairwise comparison for Market Availability Criteria

As it can be observed in the Market Availability criterion, the comparison remark that Stainless Steel 316L (A2) as the alternative with the maximum local priority. This reflects its widespread use and the consequent greater ease of finding the material for acquisition and use. In second place is Stainless Steel 17-4 PH (A1), while the alternatives with the lowest local priority are Cast Aluminum (AlSi10Mg) (A4) and Cobalt-Chrome (A7).

Cost per Kg Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	1.0000	3.0000	0.3333	5.0000	7.0000	3.0000	20.3333	0.1989	0.0057
A2	1.0000	1.0000	3.0000	0.3333	5.0000	7.0000	3.0000	20.3333	0.1989	0.0057
A3	0.3333	0.3333	1.0000	0.2000	3.0000	3.0000	3.0000	10.8667	0.1063	0.0030
A4	3.0000	3.0000	5.0000	1.0000	7.0000	9.0000	5.0000	33.0000	0.3229	0.0092
A5	0.2000	0.2000	0.3333	0.1429	1.0000	3.0000	0.3333	5.2095	0.0510	0.0015
A6	0.1429	0.1429	0.3333	0.1111	0.3333	1.0000	0.2000	2.2635	0.0221	0.0006
A7	0.3333	0.3333	0.3333	0.2000	3.0000	5.0000	1.0000	10.2000	0.0998	0.0029
							Total	102.2063	1.0000	0.0286

Figure 26: Table of alternatives pairwise comparison for Cost Per Kg Criteria

In the Cost per Kg criterion, the comparison reveals that the Cast Aluminum (AlSi10Mg) (A4) alternative obtains the maximum local priority. This result is consistent, as, in terms of cost per weight, aluminum tends to be one of the most accessible options in metallic 3D printing. The Stainless Steel 17-4 PH (A1) and Stainless Steel 316L (A2) alternatives follow, sharing the same and high level of priority. The options with the lowest priority in this criterion are Inconel 718 (A6) and Titanium 64 (Ti6Al4V) (A5), which is expected due to their nature as superalloys and the high acquisition cost of their powders or filaments.

Machinery Cost Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	0.3333	3.0000	3.0000	5.0000	7.0000	7.0000	26.3333	0.2488	0.0418
A2	3.0000	1.0000	5.0000	5.0000	7.0000	9.0000	9.0000	39.0000	0.3684	0.0620
A3	0.3333	0.2000	1.0000	1.0000	3.0000	5.0000	5.0000	15.5333	0.1467	0.0247
A4	0.3333	0.2000	1.0000	1.0000	1.0000	3.0000	5.0000	11.5333	0.1090	0.0183
A5	0.2000	0.1429	0.3333	1.0000	1.0000	1.0000	3.0000	6.6762	0.0631	0.0106
A6	0.1429	0.1111	0.2000	0.3333	1.0000	1.0000	1.0000	3.7873	0.0358	0.0060
A7	0.1429	0.1111	0.2000	0.2000	0.3333	1.0000	1.0000	2.9873	0.0282	0.0047
							Total	105.8508	1.0000	0.1682

Figure 27: Table of alternatives pairwise comparison for Machinery Cost Criteria

The Machinery Cost criterion comparison establishes Stainless Steel 316L (A2) as the alternative with the maximum local priority. This reflects that the printing technology required for 316L, such as bound filament extrusion, has the most accessible initial investment. It is followed by Stainless Steel 17-4 PH (A1), while the Inconel 718 (A6) and Cobalt-Chrome (A7) alternatives demonstrate the lowest local priority. This is because the latter materials often require Laser Powder Bed Fusion (LPBF/DMLS) technologies to achieve the necessary structural reliability, which entails an initial investment exceeding hundreds of thousands of dollars.

Post-Processing Cost Criteria										
	A1	A2	A3	A4	A5	A6	A7	Sums	Proper Vector	Proper Vector * Weighted Criteria
A1	1.0000	0.3333	3.0000	0.2000	1.0000	5.0000	3.0000	13.5333	0.1317	0.0107
A2	3.0000	1.0000	5.0000	0.3333	3.0000	7.0000	5.0000	24.3333	0.2368	0.0192
A3	0.3333	0.2000	1.0000	0.1429	0.3333	3.0000	1.0000	6.0095	0.0585	0.0047
A4	5.0000	3.0000	7.0000	1.0000	5.0000	9.0000	7.0000	37.0000	0.3601	0.0292
A5	1.0000	0.3333	3.0000	0.2000	1.0000	5.0000	3.0000	13.5333	0.1317	0.0107
A6	0.2000	0.1429	0.3333	0.1111	0.2000	1.0000	0.3333	2.3206	0.0226	0.0018
A7	0.3333	0.2000	1.0000	0.1429	0.3333	3.0000	1.0000	6.0095	0.0585	0.0047
							Total	102.7397	1.0000	0.0810

Figure 28: Table of alternatives pairwise comparison for Post-Processing Cost Criteria

And finally the Post-Processing Cost criterion comparison set Cast Aluminum (AlSi10Mg) (A4) as the alternative with the maximum local priority. This implies that aluminum is perceived as the material with the lowest post-processing cost among all options. It is followed by Stainless Steel 316L (A2), while the Inconel 718 (A6), Tool Steel H13 (A3), and Cobalt-Chrome (A7) alternatives, which often require complex thermal treatments or intensive machining, are positioned with the lowest local priority.

Synthesis and Determination of Global Priority

Once the local priorities of the alternatives under each of the twelve criteria have been established, the global synthesis stage proceeds. This phase is the cornerstone of the Analytic Hierarchy Process (AHP), as it consolidates all the judgments made within the hierarchy.

The calculation is performed by aggregating the Local Priority Vector of the seven alternatives (obtained from the 12 comparison matrices) with the Global Weighting that each criterion has on the final objective (which was defined in the hierarchy diagram).

The table below shows the result of this multiplication and summation, presenting the Global Priority that each alternative (material) obtains in the multi-criteria analysis. The material that presents the highest final value will be, by definition of the AHP, the optimal alternative for the manufacturing of critical human-machine interface components in underwater environments.

Table of Global Priority Synthesis (Derivation of Final Results)

Metallic Filament	Performance				Physical Properties			Viability		Costs			TOTALS
	Corrosion Resistance	High Temperature Resistance	Wear/Abrasion Resistance	Ultimate Tensile Strength (UTS)	Density	Biocompatibility	Hardness	3D Printing Processability	Market Availability	Cost per Kg	Machinery Cost	Post-Processing Cost	
Stainless Steel 17-4 PH	0.0243	0.0014	0.0074	0.0149	0.0051	0.0105	0.0012	0.0198	0.0029	0.0057	0.0418	0.0107	0.1456
Stainless Steel 316L	0.0737	0.0014	0.0072	0.0069	0.0051	0.0121	0.0006	0.0249	0.0053	0.0057	0.0620	0.0192	0.2242
Tool Steel H13	0.0049	0.0075	0.0337	0.0453	0.0051	0.0016	0.0034	0.0099	0.0023	0.0030	0.0247	0.0047	0.1462
Cast Aluminum (AlSi10Mg)	0.0121	0.0005	0.0027	0.0028	0.0005	0.0018	0.0002	0.0019	0.0003	0.0092	0.0183	0.0292	0.0795
Titanium 64 (Ti6Al4V)	0.0436	0.0031	0.0229	0.0149	0.0013	0.0155	0.0012	0.0077	0.0017	0.0015	0.0106	0.0107	0.1347
Inconel 718	0.0436	0.0085	0.0287	0.0289	0.0051	0.0046	0.0016	0.0058	0.0026	0.0006	0.0060	0.0018	0.1378
Cobalt-Chrome	0.0436	0.0047	0.0262	0.0149	0.0057	0.0121	0.0017	0.0099	0.0009	0.0029	0.0047	0.0047	0.1321
TOTALS	0.2458	0.0271	0.1288	0.1286	0.0279	0.0582	0.0099	0.0800	0.0160	0.0286	0.1681	0.0810	1.0000
	0.5303				0.0960			0.0960		0.2777			1.0000
	1.0000												

Figure 29: Table of Global Priority Synthesis

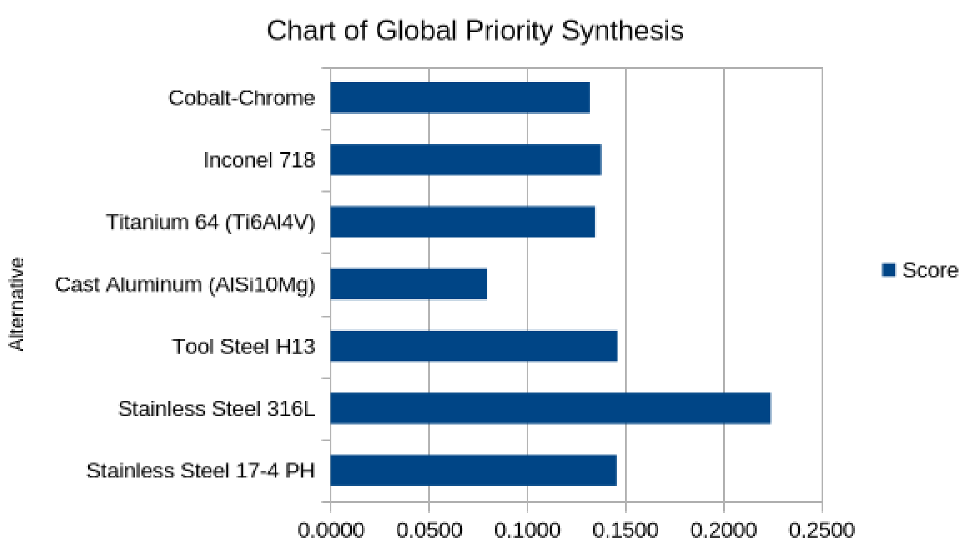

Figure 30: Chart of Global Priority Synthesis

The Table of Global Priority Synthesis represents the culmination of the Analytic Hierarchy Process (AHP), as it consolidates all the local priorities of the alternatives with the global weightings of the criteria. Each value in the matrix is the product of the alternative's local priority on a specific criterion multiplied by the global importance of that criterion. The TOTALS column on the right shows the final Global Priority of each material. This figure, which is the horizontal sum of all weighted contributions, defines the final ranking of the alternatives for strategic selection.

Based on the global priority synthesis, the Stainless Steel 316L (A2) alternative obtains the highest Global Priority with 0.2242, establishing it as the optimal material for Human-Machine Interface (HMI) components in underwater environments, as it achieves the best balance between performance, viability, and cost. The Stainless Steel 17-4 PH (A1) alternative follows with a Global Priority of 0.1456, positioning it as a strong second choice.

Crucially, it is observed that alternatives with a high local priority in the Corrosion Resistance criterion contribute most significantly to the final total, which directly reflects the decisive weight that the Performance category has on the overall objective.

VI. COMPUTATIONAL IMPLEMENTATION AND DEVELOPMENT OF THE AHP DECISION MAKER

Given the inherent complexity and the intensity of the calculations required by the Analytic Hierarchy Process, it was essential to develop an automated Decision-Maker. This system was built using Python under an "Intelligent Dashboard" architecture, whose objective is to ensure the mathematical precision of the weightings and increase efficiency in decision-making. The design is completely modular, allowing for specialized functions to be addressed in a logical sequence.

The process begins with database management. Module 1 focuses on the retrieval of information for the seven analyzed materials and, crucially, allows for the capture of new alternatives, ensuring the system can scale. In a complementary role, Module 2 ensures data precision, allowing for the update and editing of the attributes of the stored alternatives.

Once the data is ready, Module 3 (Data Visualization) offers the essential graphical support for the justification of the judgments. This module uses Business Intelligence tools through advanced graphics, such as radar and scatter plots, to visually compare alternatives, making the complex relationships of material properties intuitive.

Moving forward in the analysis process, Module 4a (Conclusion Generator) assumes a strategic support role, as it automates the drafting of a text that summarizes and justifies the selection of the winning alternative based on the Global Priority. For its part, Module 4b (Impact Index) provides a final and crucial metric, measuring the global significance of the decision on the project and its stakeholders. It is important to note that this calculation was performed based on the Grand Prix model to establish the impact scale.

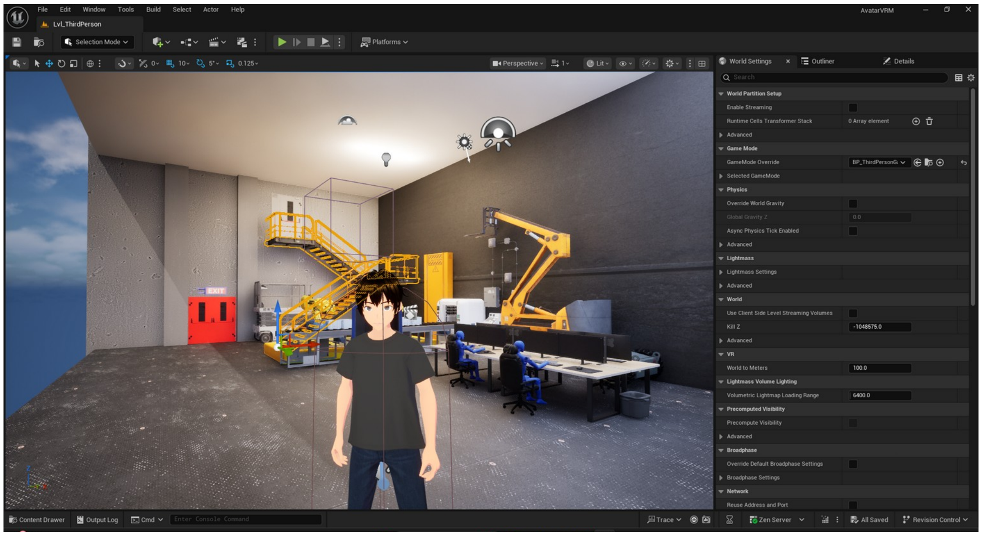

Figure 31: Development of the Scenario Created in Module 5 for the Presentation Using a Virtual 3D Model from VRoid

For the introduction and presentation of the project, Module 5 (Narrative Introduction) was developed. This resource leverages the potential of the Unreal Engine 5 graphics engine to create an immersive experience, beyond a simple video presentation. The functionality focuses on animating a virtual presenter character (Vroid) that uses lip synchronization with audio generated by Artificial Intelligence. This module seeks to capture the viewer's attention and lay the groundwork for the analysis in an engaging way.

The system integrates rigorous sustainability metrics and human factors. Module 6 (Ecological Footprint Determination) allows for the quantification of the environmental impact of each alternative. This analysis is fed with variable data such as energy and water consumption or waste and CO2 production, integrating the dimension of sustainability into the final evaluation. Similarly, Module 7 (Psychosocial Factors) integrates the human perspective by quantifying, through a survey, the influence of material acceptance and work environment on the decision, thus completing the holistic vision of the analysis.

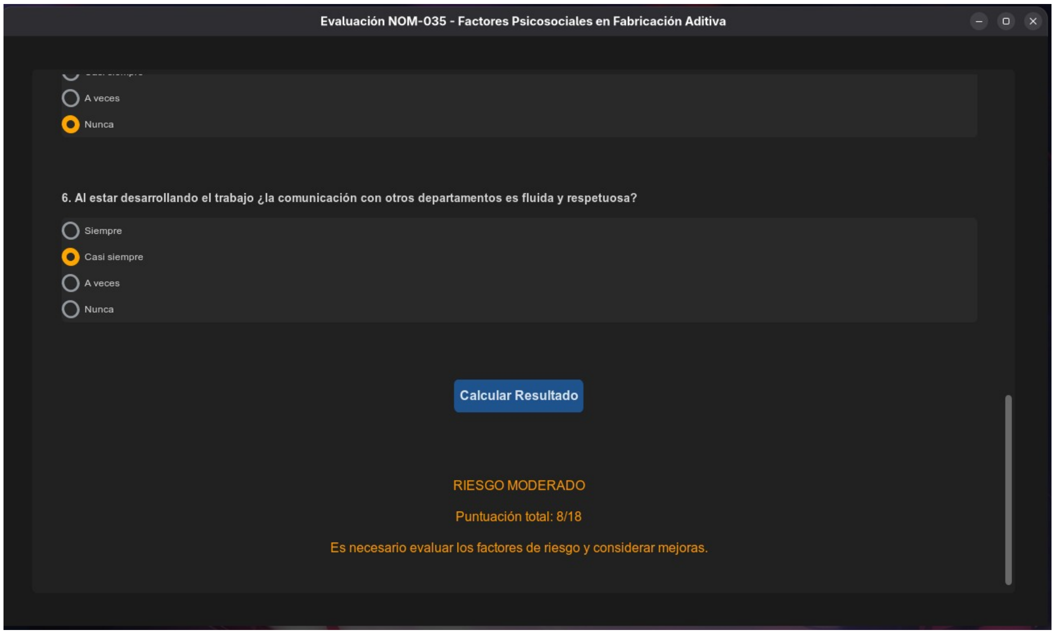

Figure 32: Survey Development for Psychosocial Factor Calculation

Module 8 (Multi-Criteria Comparison) is the main mathematical component and the engine of the Global Priority. Its function is to execute the Multi-Criteria Decision Making (MCDM) process. It not only performs the AHP calculation but also validates it with complementary methodologies such as MOORA and VIKOR, which provides a superior level of robustness to the final material ranking.

The analysis of the three Multi-Criteria Decision Making (MCDM) methodologies AHP, MOORA, and VIKOR was carried out to establish a robust ranking of the alternatives, with each graph presenting the options in order from best to worst classification.

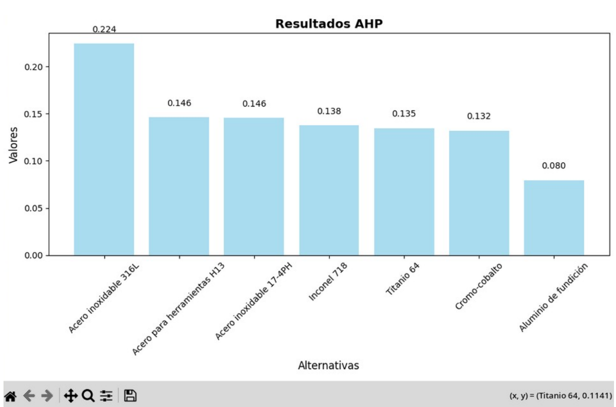

Figure 34: AHP Results Obtained Based on Module 8

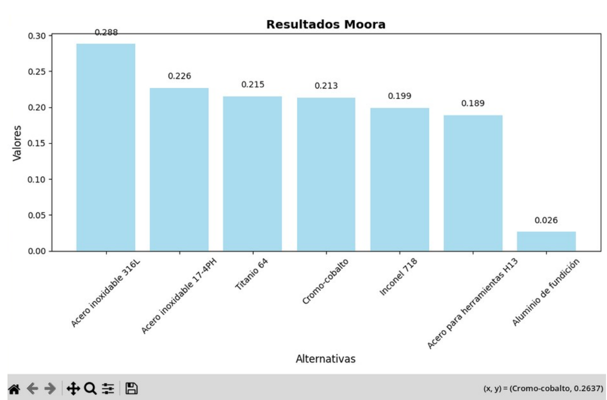

Figure 33: Moora Results Obtained Based on Module 8

The Analytic Hierarchy Process (AHP) and MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) show strong convergence. Both methods identify Stainless Steel 316L (A2) as the optimal alternative and Cast Aluminum (A4) as the worst option for the project's objective.

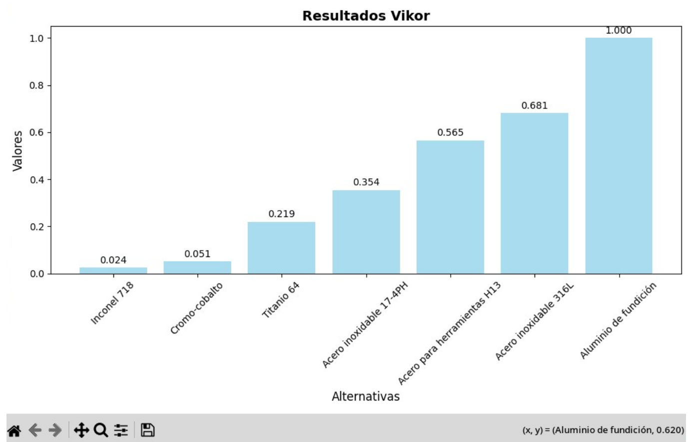

Figure 35: Vikor Results Obtained Based on Module 8

The VIKOR Method introduces a different perspective, as it seeks the compromise solution that minimizes the risk of selecting a significantly worse alternative. Under this model, VIKOR classifies Inconel 718 (A6) as the best alternative, ahead of Stainless Steel 316L (A2).

This difference is explained because Inconel 718 achieves excellent performance in the most critical Performance criteria, which better compensates for its disadvantages in the Cost and Viability areas. By prioritizing this compensation, the VIKOR method minimizes the possibility of the part failing due to a mechanical factor, which is the highest risk in an underwater environment. Nevertheless, the method concurs with AHP and MOORA by positioning Cast Aluminum (AlSi10Mg) (A4) as the worst alternative in the ranking.

Despite this slight difference in the first place (A2 versus A6), the robustness of the multi-criteria analysis is confirmed by the solid agreement among the three methods. This consensus is based on two irrefutable points: the total discarding of Aluminum (A4) and the high proximity of Stainless Steel 316L (A2) and Inconel 718 (A6) at the top of the rankings. This validates that the optimal solution is bounded and confirmed between these two high-performance materials.

Finally, Module 9 ensures the traceability and documentary reference of the project, by providing direct access to the full report's PDF document through an integrated button on the Dashboard.

VII. RECOMMENDATIONS FOR FURTHER RESEARCH

One line of research that could be applied to improve the certainty of this study is the validation of performance data. This involves replacing the obtained values with direct experimental results from corrosion and mechanical resistance tests performed on printed parts under simulated underwater pressure and salinity conditions. This would allow us to obtain absolute certainty regarding the Local Priority of the alternatives in the Performance criteria, strengthening the technical basis of the decision.

Another necessary line of action to give greater validity to the model is the expansion of expert judgment to mitigate any possible bias. This would be achieved by validating the initial pairwise comparison matrices with a broader and more diverse panel of specialists in engineering, additive manufacturing, and project economics. This would allow us to obtain a more robust consensus in the initial weightings of the criteria, thus increasing the reliability of the Global Priority Vector.

Another improvement that could be applied to the computational model is the integration of a formal sensitivity analysis within the software. This tool would allow for the evaluation of how small changes in the weight assigned to the Performance category would affect the Global Priority. This would allow us to confirm the stability of the obtained ranking.

VIII. CONCLUSIONS

This study, based on the Analytic Hierarchy Process and assisted by the Modular Decision Maker implemented in Python, has robustly and conclusively determined the strategic selection of the optimal material. Stainless Steel 316L is established as the winning alternative with the highest Global Priority, fulfilling the objective of finding the best balance among Performance, Viability, and Cost for critical components in underwater environments.

This selection is fundamentally based on the fact that the high local priority of 316L in the Corrosion Resistance sub-criterion directly aligns with the decisive weight of the Performance category on the overall objective. The validity of the result is reinforced by the consensus among the three MCDM methodologies (AHP, MOORA, and VIKOR) which, although differing slightly in intermediate positions, totally concur on two critical points: ratifying 316L and Inconel 718 as the two superior options and discarding Cast Aluminum as the worst alternative.

The rigor of the analysis was supported by the Decision Maker, which automated the calculation of all matrices, integrated complementary analyses such as the Ecological Footprint and Psychosocial Factors, and provided a clear visualization of the results. Finally, while the current model is robust, it is recommended that future research focuses on the empirical validation of data and the integration of a sensitivity analysis to guarantee the stability of the ranking against any variation in the initial weightings, thus consolidating the transfer of the model to industrial application.

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