Cost Profile of 3D Printing Using Biomaterials on a Lab Scale

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Abstract: Additive manufacturing is a term used for the type of technologies aiming to manufacture objects by layering materials in specific geometric shapes. 3D printing technology may be financially lucrative; however, safety risks could arise, thus generating different types of potential costs, including economic losses. This work aims to explore such challenges faced by laboratories that use 3D printing technology, emphasizing the relationship between safety and economics in decision-making processes. Qualitative and quantitative methods were thus employed to address the challenges met by laboratories when manufacturing 3D printed biomedical products. The concept of the Total Cost of Ownership (TCO) was used to identify the corresponding costs for Fused Deposition Modelling (FDM) and stereolithography (SLA) by considering the assessment of the processes' accident cost. The quantitative analysis revealed that the most significant parameter impacting the TCO of the FDM and SLA is the labor cost, which comprises over 95% of the total cost. Therefore, reducing 3D printing costs on a lab-scale should be a priority for any 3D process. Other processes can take advantage of the same solution by addressing this issue, thus allowing for more accurate cost comparisons of products created using different processes.

Keywords: 3D printing; cost; fused deposition modeling; stereolithography; TCO; ABC.

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1. Introduction

Three-dimensional (3D) printing or additive manufacturing (AD) for the creation of objects through the use of a 3D printer and a digital file with specifications detailing the characteristics of those objects has become exponentially more popular in the past few years [1–14]. The expressed interest in 3D printing has significantly grown in the past decade. It is anticipated to reach $21 billion by the end of 2021, owing to its singular assets, including sustainable and efficient production and a swift transition from design to manufacturing, as opposed to other methods [15].

Significant research has been conducted about the exploitation of biomaterials in 3D printing, emphasizing biomedical applications [16–18]. The available literature indicates that depending on their chemical profile, they are generally categorized into four main groups: metals and respective alloys (such as titanium, steel, etc.), ceramics and carbon mixtures (such as glass, alumina, and titania), polymers (polycarbonates, polyurethanes), composites (such as
dental filaments) [19]. Different methods and biomaterials have been investigated including, bone tissue engineering [20,21].

AM can be categorized into solid, powder, or liquid-based depending on the chosen base material. Fused Deposition Modelling (FDM) is the most traditional and frequently applied solid-based 3D printing method to manufacture polymer parts. FDM is a typical example of an extrusion method and is regarded as the most widespread and cost-effective additive manufacturing technology, thus contributing to its popularity [18,22]. SLS is a well-known AM polymer parts production method relying on the use of polymeric powders as the main component. At the same time, SLA is another popular AM method based on processing polymeric liquids [23].

Additive manufacturing has very promising prospects. Thus, many efforts have already been devoted to making it financially viable. According to field experts, financial progress, material usage, and environmental effects have been closely connected [24]. It is not easy to consider a future where separating these notions would be feasible. Such arguments echo ongoing scientific deliberations about the likelihood of decoupling [25,26], which have an established history as part of the wider question on the reconciliation of environmental and financial objectives.

Product engineering covers the whole process, from the design to the development of a product. During all stages of product development, a key element is a financial analysis [27]. Furthermore, 3D printing is increasingly used in medicine, including patient-specific instrumentation. A key element of the use of 3D printing in medicine is the materials used, which directly impact the quality of the final product, the time it will take to complete it, and its cost, which directly affects the process of Product engineering.

Nevertheless, manufacturing can be expensive, demanding financial support in various aspects. The financial impact can be positive or negative, depending on the circumstances, the worth people assign to them, or existing standards. As a result, costs are a crucial parameter when evaluating the viability of any project and preparing to make informed decisions [28]. If the stakeholders do not gather enough funds, then the adoption of the technology will not be successful [29]. The reduction in manufacturing costs has been examined in previous studies, according to which managers should establish strategies leading to sustainable projects, hence achieving financial profits [30].

In terms of financial feasibility, implementing AM processes in either existing or new environments requires a dependable financial model that enables investment decisions. The capacity to predict the production cost of a part is critical to various laboratory activities, not only during pricing and planning but also while still in the design stages, where all aspects of the potential manufacturing solutions should be considered [31]. The cost of the produced part depends on multiple factors such as any potential preparation costs, environmental measurements, and the actual implementation stage [32]. It further includes the 3D printer’s depreciation cost [33], the finishing process [34], electrical bill [34], and labor cost [35].

Alexander et al. [36] were the first to attempt to model the AM cost, establishing a general cost evaluation system for additive manufacturing, which computed the total cost by combining the costs required before, during, and after build. There is a lot of prior research attempting to use an activity-based approach to identify and compute the related costs [37–39]. A frequently accepted definition [40] that offers the first insight into the TCO concept suggests that the TCO methodology is based on activities, utilizing corresponding methods to analyze and assess the related costs [5]. In such cases, indirect costs are usually distributed according
to the time requirement of activities during the AM workflow. Indirect or overhead costs are defined as the costs that are only indirectly connected to the product, such as occupational injuries and severe illnesses [41].

Chao Chen proposed a minimal cost approach, in which the potential accident cost should be considered [42]. Laboratory accidents often occur and threaten health and safety; they may significantly affect a laboratory's budget [43–45]. However, costing is a time-consuming process; scientists should thus carefully consider concessions in terms of the accuracy and precision of the assessment [46]. To the best of our knowledge, there has been no previous research on occupational accidents related to 3D printing on a lab-scale and the economic repercussion thereof. This knowledge gap calls for the creation of a novel cost model aiming to address this issue, as presented in this work. The proposed model extends previous cost modeling formulations available in the literature and proposes a TCO model for 3d printing that includes the factor of accident cost in two case studies in terms of FDM and SLA processes at a lab scale. The outcomes of this research may offer better support through the decision-making process.

This study is organized in sections: Section 2 establishes the cost model, Section 3 describes the outcomes and presents two case studies related to different lab processes that were utilized to showcase the actual use and capabilities of the suggested model, while a conclusion is drawn in section 4.

2. Methodology

2.1. 3D printing process case study.

This quantitative research study focuses on custom 3D printed bone.

2.2. Qualitative data.

Qualitative factors were explored through interviews with a lab manager used as an expert source of knowledge. The selected expert had to meet certain criteria to ensure that they could offer correct insights and support the research design and goal. This selected expert is an experienced professor who works as a lab manager and whose knowledge helped move the research forward after a series of interviews. The interviews were held in his office and were thorough, lasting at least one hour each. The interviews aimed to allow the expert to openly express his unbiased opinion without using predefined statements, which ensures the objectivity of the created model that can be generalized and allow for the inclusion of other types of 3D Printers.

Data was also retrieved from logbooks that contained daily entries by the researchers, keeping records of multiple experiments. Every logbook entry presented is date/time signed/stamped from the manager [47].

2.3. ABC method.

The ABC method is a systematic approach aiming to obtain information about all activities, commonly via interviews or observation by the researcher [46]. The suggested cost model is based on a structure guided by the main stages of the 3D printing process. It requires three steps to be taken: (i) pre-printing activities, aiming to prepare the system; (ii) the printing
stage, during which the part is manufactured; and (iii) post-process actions, with a focus on extracting, inspecting, and processing the parts post-production.

Before reaching the process stage, a CAD model of each part is used as input. The provided model is introduced into software, and the operator chooses the orientation and support for each part. During this stage, the presence of an experienced researcher is required, while no human presence is needed for the actual printing process. As soon as processing is completed, the build should be extracted. The parts are separated from the baseplate; they are then examined and further processed according to specifications and application needs. Post-processing activities may include but are not limited to surface finishing and thermal treatments.

The ABC approach took into account all the activities related to using a 3D printer over its lifetime (Figure 1).

**3D PRINTING PROCESS**

![3D Printing Process Diagram](image)

**Figure 1.** Schematic representation of the 3D printing flow of the FDM and SLA components.

All relative activities and cost parameters were identified, thus creating a TCO model for additive manufacturing. The Activity information can be gathered through various typical approaches, such as time studies, observation, expert interviews, questionnaires, or a combination thereof. Any activity is a source of cost, so it is important to have information about what each process entails. The cost has two main components: resource materials and process costs.

### 2.4. Quantitative data: Generic TCO Cost Model for FDM and SLA processes.

The TCO model includes individual factors that have been defined, examined, and computed into the result.

\[
TCO_{3d} = C_R + C_E + C_L + C_M + C_D + C_A
\]  

(1)

where

- \( C_{sp} \) is the total cost of ownership of the 3D printing process
- \( C_R \) - Raw Material Cost
- \( C_E \) - Energy Cost
- \( C_L \) - Labor Cost
- \( C_M \) - Maintenance Cost
- \( C_D \) - Depreciation of apparatus and equipment
- \( C_A \) - Accident Cost
Ellram [40] proposes that Pareto’s law is appropriate when identifying the cost factors. Pareto’s law claims that 20% of the cost factors contribute to at least 80% of the total cost. This law is mostly a general hypothesis rather than the rule, and the percentages do not have to be exactly 20 and 80%, respectively. The theory emphasizes that a small number of cost factors are often accountable for the majority of the total cost. According to that concept, the following hypotheses were formulated: Raw material cost has the strongest influence on the TCO of the synthesis process and accounts for at least 80% of the total costs.

The suggested model depends on the assumptions listed below:

2.4.1. Raw material cost.

Tretyak & Sloev propose the virtual incorporation of clients into the innovation of a business process through an interactive process, which permits the establishment and distribution of value [48]. As a result, the main objective in this phase was to discover the market prices for the studied materials and printers and explore the options of the commercial catalog of each vendor [49]. More specifically, the suppliers for the raw materials were Formlabs (USA) and Smart Materials 3D (Spain), based on data accessed in July of 2021.

\[ C_R = \sum_{i=1}^{n} (U_i \ast N_i) \]

where

- \( C_R \) is a raw material cost in (€)
- \( U_i \) = the price per unit for material \( i \) (€/unit)
- \( N_i \) = the number of units for material \( i \) (number of units)

2.4.2. Labor cost [49].

Before calculating the labor cost, it should be noted that specific assumptions have been made about the typical laboratory conditions: one year comprises 250 working days, and one working day counts for 8 working hours. The personnel required for the 3D printing of biomaterials is one experienced researcher occupied for about 6 actual person-hours for SLA and 5.67 hours for FDM2, though the full process requires about 20 hours. Labor costs were retrieved as average wages from Glassdoor [50] due to the large database offering salary data based on specified positions and countries. They also provide information on how the average wage has been calculated (how large the sample, minimum and maximum amounts, etc. In Greece, the average hourly wage of an experienced researcher reaches about 60.00€.

\[ C_L = w_i \ast h_i \ast n_i \]

where

- \( C_L \) is the total labor cost in (€)
- \( w_i \) = the hourly wage of category \( i \) (€/hour per person);
- \( h_i \) = the number of hours of category \( i \) (hours);
- \( n_i \) = the number of employees of category \( i \) (number of people)

2.4.3. Energy cost.

Energy consumption has been estimated according to the approach suggested by [51], who proposed focusing on breaking down the energy usage of each apparatus utilized in the
studied activities. This approach has three steps, starting with the identification of required equipment in an attempt to evaluate their nominal power. This information can be found in the technical books provided by the equipment vendors. It is higher than what is actually spent during the process; however, it acts as a point of reference when it is not possible to do more accurate measurements. The last phase involves the estimation of the duration that each apparatus was used, based on what is being printed [52]. Once the information is gathered, it is possible to calculate the actual energy consumed by using the following formula:

\[ C_E = P_D \times t \]  

(4)

where

- \( C_E \) is the cost of energy,
- \( P_D \) = the nominal power of the apparatus (kW),
- \( t \) = the usage time of the apparatus (hours).

The final result should take into account the load factor:

\[ C_E = P_D \times a \times t \]  

(4.1)

where \( a \) is the Load Factor (0 < LF < 1)

After reviewing the reference books related to the 3D printers, the nominal electric power consumption was thus identified. Considering that the specifications provided the required time, the only unknown variable remaining to be evaluated was the load factor. The cost has been evaluated as the amount of KWh used multiplied by the price per KWh in Euros (Greece). Based on EU Data, the price corresponds to the average price for 2020. The prices originate from the Greek Public Power Corporation [53]. Once this data was available, adding the energy dimension into the model became possible.

2.4.4. Maintenance cost.

Decrepit materials require replacements, which occur during lab equipment maintenance [49]. The maintenance costs include both potential replacement costs and the costs stemming from the activities of employees throughout the process.

\[ C_M = u_i n_i + w_i h_i n_i \]  

(5)

where

- \( C_M \) is the maintenance cost,
- \( u_i \) = the price per unit for material i (€/unit);
- \( n_i \) = the amount of units for material i (number of units).
- \( w_i \) = the hourly wage of category i (€/hour per person);
- \( h_i \) = the number of hours of category i (hours);
- \( n_i \) = the number of employees of category i (number of people)

2.4.5. Depreciation cost.

Depreciated cost is referred to as the cost of an asset after the depreciation amount has been subtracted. It is the part of an asset that has not been consumed in full yet. The annuity concept is commonly used to make annuity calculation easier. The annuity method can be used when yearly net operating revenue is consistent, and the replacement cost of the equipment is not subject to change [49]. Therefore, the total outcome combines interest and depreciation.
After every year, the equipment value will be equal to the discounted present value of the annuity payments left, while the depreciation cost will be equal to these values.

\[
P = PV \cdot \frac{r}{1 \cdot (1+r)^n}
\]

(6)

where

\begin{align*}
P &= \text{Payment} \\
PV &= \text{Present Value} \\
r &= \text{rate per period} \\
n &= \text{number of periods}
\end{align*}

The annuity factor allows for quick calculations when assessing the payment on an annuity with a known current value. This might be done by creating a table to locate the specified rate and period number factor. In regards to the annuities of an investment cost, a discount rate of 3% and an expected lifetime of 10 years is calculated for Form2 (SLA) and a lifetime of 7 years for Zortrax M200 (FDM).

2.4.6. Accident cost.

Manual bed leveling is a tricky process. It can be time-consuming and frustrating. 3D printer bed leveling is extremely important to successful printing as it allows the extrusion of materials on the build surface [54]. For this study, an experienced researcher conducted the calibration to improve the process's accuracy. The researcher slightly burned his right arm during the bed leveling process due to equipment failure. The accident was categorized as one of "low severity" [55] due to the minor extent of the injury, requiring only a few days off work. Equipment parts were ordered and replaced. No further action was required.

\[
C_A = C_{MT} + C_{TR} + C_{RS} + C_{RE} + C_{HB} + C_{IB} + C_{OC}
\]

(7)

where

\begin{align*}
C_A &= \text{the yearly accident cost (€)} \\
C_{MT} &= \text{the cost for medical expenses (€) = C_m \cdot n is the medical cost x number of injured employees, no travel expenses} \\
C_{RS} &= \text{the salary cost for replacement staff (€) = } \sum (w_i \cdot h_i \cdot n_i) \text{ hourly wage of category } i \text{ x hours spent x number of employees} \\
C_{TR} &= \text{the training cost for replacement staff (€) = } \sum (w_i \cdot h_i \cdot n_i) \text{ hourly wage of category } i \text{ x hours spent x number of employees} \\
C_{RE} &= \text{the cost of replacement of equipment (€) = A + B + C damage to } \text{equipment+damage to infrastructure+damage to raw materials} \\
C_{HB} &= \text{the cost of human benefits (€/year) = C1 \cdot n1 + C2 \cdot n2} C1 , C2 = \text{the cost of one light injured and serious injured worker (D/person); n1 , n2 = the number of light injured and serious injured workers (# injured persons)} \\
C_{IB} &= \text{the cost of insurance benefits (€/year) = P \times Ip Current premium*expected increase in premium (%)} \\
C_{OC} &= \text{other costs, i.e. cleaning and root cause analysis (€/year) = } \sum (w_i \cdot h_i \cdot n_i) \text{ hourly wage of category } i \text{ x hours spent x number of employees}
\end{align*}

\[
C_R = (C_A / H) \cdot h_i
\]

(7.1)

where

\begin{align*}
C_A &= \text{the yearly cost of accident in Euros (€)}
\end{align*}
\[ h_i = \text{the total number of hours of category } i \text{ (hours)}; \]
\[ H = \text{the total number of working hours in a year (1920)} \]

3. Results

3.1. 3D printing.

Dimensional accuracy is of great interest, and since two different 3D printing technologies are employed, an assessment of the accuracy of the printed specimens versus the digital geometry was applied. Six specimens were 3D printed, 3 with each 3D printing method, with 3 different layer heights (50, 100, and 150\(\mu\)m). In order to conclude comparable results, the orientation of the specimens during 3D printing was kept the same. Figure 2 illustrates two specimens printed with different methods where the supports are clearly presented. The contact points of the supports with the specimens are regions where dimensional accuracy is compromised.

![Figure 2. Bioprinting bone through (a) SLA; (b) FDM.](image)

The application is depicted as applied on two different components, case 1 Dental LT¹ (SLA, Figure 2a) and case 2 Smart Materials 3D - Medical² (FDM, Figure 2b).

![Figure 3. Geometric deviations between the 3D printed specimens and the modeled geometry.](image)
After post-processing, the specimens were scanned using a μCT scanner (Werth Tomoscope HV Compact 225 3D CNC) with the following scanning parameters (magnification 100L, current 500μA, voltage 80kV, exposure time 250ms, number of projections 2 and number of steps per rotation 1600). After the geometry reconstruction procedure, the digital files were imported into an STL editing software, where the scanned geometries were compared to the modeled one.

In Figure 3, the geometric deviations are shown. Although the specimens printed with the SLA method have smoother surfaces (layering is visible on the FDM specimens), the maximum deviations have almost the same values compared to those printed with the FDM method, with a range between 0.11 0.29mm. Also, as was expected, deviations grow larger with the layer height.

3.2. Total cost of ownership.

The TCO study focused on identifying and assessing the costs related to the two selected printers, which are: Form2 (SLA process) and Zortrax M200 (FDM process). The examined printers belong to the Faculty of Sciences and are used in research. The resulting cost components were categorized accordingly. To define the cost profiles of each of the alternative 3d printing processes under investigation, the costs savings were considered for each case – raw material cost, energy cost, labor cost, maintenance cost, depreciation cost, and accident cost. Based on the developed model, the total cost of ownership for the two processes is presented in Table 1. Table 1 illustrates the cost profiles for FDM and SLA processes. In this case, labor cost ranges between 340€-360€ and is the main cost driver of the TCO for both cases. Comparable processes are investigated, and different methods have been used for each process.

| 3D Printing Costs       | FDM     | SLA     |
|-------------------------|---------|---------|
| Raw Material Cost       | 2.35 €  | 18.20 € |
| Energy Cost             | 0.71 €  | 0.27 €  |
| Labour Cost             | 340.00 €| 360.00 €|
| Maintenance Cost        | 0.06 €  | 0.07 €  |
| Depreciation Cost       | 1.60 €  | 0.27 €  |
| Accident Cost           | 42.11 € | 42.11 € |
| TCO of 3D printing      | 386.84 €| 420.92 €|
| TCO After Discount 3%   | 375.23 €| 408.30 €|

Figure 4. Percentage distribution of TCO cost factors per studied 3d printing process.
Labor cost ranges from 340€-360€ and is the main cost driver of the TCO for both processes. Aggregate results of the analysis indicate that SLA has the highest TCO.

Figure 4 provides a direct comparison of the cost distribution for the two processes of the study numerically and graphically.

The shares of depreciation (0-0.43%), maintenance (0-0.2%) and energy (0-0.19%) between FDM and SLA processes are more uniform. The TCO for both FDM and SLA is highly impacted by labor and accident costs. Labor cost accounts for more than 88% of the total cost of ownership for FDM and SLA process. All other costs are relatively less significant.

4. Discussion

3D printing has received growing interest in producing complex engineering constructs [56]. Medical 3D printing utilizes many biomaterials, including metals, ceramics, polymers, and composites [57]. Despite the multiple milestones achieved, there are still multiple challenges to the growth of this technology, such as the development of cost-efficient but high-performance biomaterials.

Cost is a significant factor in decision-making that helps verify the economic viability of any potential investment, and costs related to 3D printing set limits to its growth [58]. 3D printing nowadays usually includes pre- and post-process steps that need to be taken into account when preparing a budget [59]. Some indicative costs that should be part of the equation are the ones related to material, equipment, labor, and energy consumption [60,61]. The objective of this work was to analyze AM, focusing specifically on FDM and SLA printing, in terms of a cost point of view, including the indirect costs of 3D printer usage over their lifetime, with an emphasis on accident-related costs. Due to their numerous health applications and complexity, 3D printing invites a TCO perspective as the unit of analysis. A generally accepted definition is offered from (L. Ellram, 1993), who describes the TCO concept as an activity-based method using activity-based costing (ABC) principles to assess the costs. The main conclusions stemming from such a definition are that: a) it is an activity-based technique, b) it can be useful in evaluating costs, which became the starting point for this study.

The TCO approach has been deemed as suitable for the evaluation of such a potential, taking into account that this technique considers more than just the market price, by including a wider range of known and unforeseen or not easy to estimate costs in the decision-making process, thus offering a broader analysis of all related costs. The use of the TCO approach on AM requires the following steps: (1) establishment of a generic framework for the establishment of the cost parameters, (2) use of the model adjusted for typical SLA and FDM printers to make comparisons, and (3) identification of the factors with the highest impact on the cost components [62–64].

The case studies revealed that quantitative evaluation is a decisive factor. Regarding the level of novelty, the methods were employed in original and adaptable design cases. The concept of TCO models was employed to provide quantitative estimates. Comparing the two case studies, especially when considering the accident cost, reveals an interesting outcome. The application of the TCO model on AM aims to identify ways to achieve cost savings [65]. As a result, the advantages of using the total cost of ownership approach are diverse and impactful. Hopkinson and Dickens appraised the total production cost for the parts through AM comparing parts created through additive manufacturing via injection molding. The total cost was classified into equipment, resources, and labor costs. Machine power was ignored during the cost estimation [66]. Alexander et al created a cost evaluation system, which was further
adapted for both FDM and SLA. Manufacturing costs, estimated per part, are allocated to the process phases before, during, and after processing. Process times are specific per phase, and the relative activities can be further divided into people- and equipment costs. This cost is thus considered activity-based [36].

Two types of printers were selected for the research, which enabled the discovery of corresponding cost factors and real costs of AM and provided explanations on the importance and variation of cost parameters, drawing to the following conclusions. For this work, the costs considered include the pre- and post-processing costs such as accident cost, energy, 3D printer cost, equipment depreciation, maintenance cost, material cost, and researcher wages. By defining the direct and indirect costs to the corresponding processes that induce them, ABC allowed managers to understand the costs and gains related to each product.

However, in the cases of FDM and SLA processes, no support for the null hypothesis was found, where accident and labor costs were the main determinants. For these processes, the raw material cost was insignificant. The realization that a relational connection did not happen might be interesting to explore since it could highlight that the null hypothesis heavily depends on technology, equipment brand, printing materials, and the shape of the result. The cost of raw materials is generally high compared to typical manufacturing processes. Thus, they are most commonly used for high-value products or when time is an issue [58]. Labor costs could be further reduced, especially when products are made in one piece [67].

However, it should be noted that there are often difficulties in extracting exact measurements, especially isolating the exact voltage and current an instrument uses or identifying the exact wage ranges per occupation and position in each country [68]. To allow for comparisons of the various 3D printing processes, a full list of resources and equipment that are used in all stages is required. Temporal differences might be a possibility as well. Generally, processes might evolve, and impact evaluations improve over time. It is thus crucial to identify and balance any temporal aspects of the assessment.

Towards the 3D printing process and the relevant TCO the main limitation in this study was that the focus is limited to FDM and SLA processes. However, the current process neglects other types of 3d printing processes and materials that were circumvented through privileged access to data and people. Evaluating the qualitative evidence from the test case studies, and more specifically the contextual factors that can facilitate cost savings, focus on the importance of safe investments and the avoided accident cost factor. Moreover, 3D printing has various applications, each with its economic implications, considering that prices vary significantly from one country to another, thus producing diverse results. An example variable that might cause this diversity is the energy cost, which is not universal. The system's efficiency, processes, and maintenance requirements also play an important role [69].

4. Conclusions

Through the establishment of a new cost model and its related parameters regarding the process of 3D printing using biomaterials, this study has offered two contributions. The first one relates to the incorporation of accident costs in the process. Moreover, quantitative results from the case studies shed light featured the actual need and economic potential. The model was presented through two illustrative case studies so that the necessary phases to analyze, methods, and information was defined. This aimed to explore common process characteristics to identify potential patterns. The results showed that the labor cost attribute is the most significant factor impacting the TCO. Although TCO evaluations are very dependent on the
specific cases and generalized frameworks are not appropriate, none of the identified cost drivers are solely for FDM and SLA processes. The TCO model can be generalized to other types of processes.

Aside from its theoretical contributions, this work also offers a guideline to aspiring laboratory managers and researchers. Circularized information within a 3D printing network may add value by uncovering the essential domains to handle cost risks more effectively. This work contributed to the current knowledge on the cost of 3D printing by uncovering knowledge gaps and proposing to support laboratories and researchers on the definition of the issue and required data and processes to assess the cost of their products.

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**Conflicts of Interest**

The authors declare no conflict of interest.

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