Towards Environmental Sustainability in Digital Fabrication Classes

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Abstract

This paper reports the challenges of introducing bio-based materials to designers for generating awareness in environmental sustainable prototyping. We conducted a workshop with 22 novice students to introduce the environmental impact of prototyping materials and creating hands-on experiences with biodegradable materials and digital fabrication techniques. We reported novice designers' decisions on materials from low to high fidelity prototyping and their perception of using mycelium-composite for Digital Fabrication. We presented a discussion of implications for educators to address environmental sustainability in their lab or when teaching digital fabrication in a classroom.

Author Keywords

prototyping; biomaterials; mycelium; sustainability; digital fabrication; sustainable design

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI);** *Haptic devices;* User studies; Please use the 2012 Classifiers and see this link to embed them in the text: https://dl.acm.org/ccs/ccs_flat.cfm

Introduction

Digital fabrication has been a powerful tool for researchers, companies, and makers, however, it generates an environ-

	Degradation Time	Recycle	Compost
Biomaterial (mycelium)	90 days	No	Yes
MDF (Fiberboard)	13 years	No	No
Acrylic	400 years	Yes	No
Cardboard	2 years	Yes	Yes
Fabrics (nylon, polyester)*	30-200 years	Yes	No

Figure 1: End of Life of common prototyping materials and mycelium-composite [3], [7], [10].

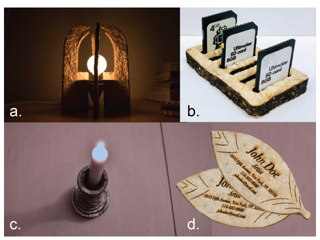

Figure 2: Mycelium-composite sheets laser cut to make different prototypes samples.

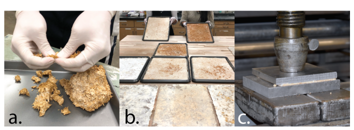

Figure 3: Manufacturing process in the lab to make mycelium-composite: a. Breaking down the material, b. Growing the materialin molds, c. Compressing the material.

mental impact due to the use of traditional materials that can take over 100 years to degrade, the huge amount of wasted material generated from unused prototypes, left-overs, and mistakes during prototyping. There are some approaches in applying DIY tools for biomaking [6] [4] [7] [5] [1] [9] however they did not aim to use biodegradable materials as a prototyping material for digital fabrication. Mycelium is a fast-growing vegetative part of a fungus which is a safe, inert, renewable, natural and green material which grows in a mass of branched fibers, attaching to its environment [2]. Mycelium based materials have a wide variety of applications and they have the advantage of the low cost of their raw materials [2]. Other advantages are its naturally non-flammable, good at insulation, lightweight, variable strength capacity, shapeable and hydrophobic properties, which makes it adequate to use it as a biomaterial for prototyping [8], [11], [12].

Sustainable Prototyping Workshop

The main purpose of the Sustainable Prototyping workshop was to understand participants' reflections about the environmental impact of materials. We conducted this workshop with 22 novice design students. The participants didn't have previous experience with digital fabrication techniques (laser cutting and 3D printing), and on working with mycelium. They were second and third-year undergraduates with no compensation for their participation in this workshop. Fig. 1 presents data about the degradation time of common digital fabrication materials and its possibilities to recycle or compost. This Fig. 2 shows the samples we prepared for the workshop.

The workshop was divided into three sessions that happened two times. Fig. 4 shows the Instructional Plan used for the first session (3 hours). During the hands-on activity of this session (Cycle 2 and 3 happened in parallel), participants were asked to design an electronic component enclosure using a 2D program such as Adobe illustrator. They were allowed to iterate up to 3 times and pick their preferred material to laser cut between matboard, acrylic, plywood, and mycelium-composite. Participants had two days to complete this assignment as part of the workshop. Participants completed two questionnaires at the end of the first session and the second, to collect student's reflections about materials' impact before and after interacting with bio-materials (mycelium). We used open-ended questions in both questionnaires about their materials' decision-making.

Anticipatory Set (30 minutes) 1. Prototyping process: Sustainable Design, Lifecycle, Biomaterials. 2. Impact of Prototyping materials in the environment; use and end of use while DIY prototyping.	
Presentation Cycle 1 1. Instructions on use of mycelium (molding and lasercut), samples made with different prototyping materials. **(8 minutes)**	**Practice Cycle 1** 1. Hands on activity: Personalize prototype using a basic template shared with the class. **(22 mins)** 2. Iterations after failings **(20 mins)**
Presentation Cycle 2 1. Laser cutting an electronic enclosure (materials provided in class) **(2 minutes)**	**Practice Cycle 2** 1. Laser cut their customized design in groups of 6 students in the prototyping lab. **(58 minutes)**
Presentation Cycle 3 1. Mold making an electronic enclosure (circuit playground) or a lampshade. **(2 minutes)**	**Practice Cycle 3** 1. Students will mold with mycelium composites using their objects brought to the class. **(58 minutes)**
Wrap up (20 minutes) Students' feedback on experience prototyping with an eco-material Review the learning outcomes of the day	

Figure 4: Instructional Plan for the Sustainable Prototyping Workshop

Figure 6: Workshop: Participants in hands-on activity and mold making with mycelium

Figure 7: Left to right: iteration 1 (mycelium composite), iteration 2 (acrylic and mycelium), iteration 3 (acrylic)

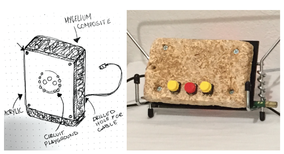

Figure 8: Mycelium speakers: Novice designer's sketch and final prototype

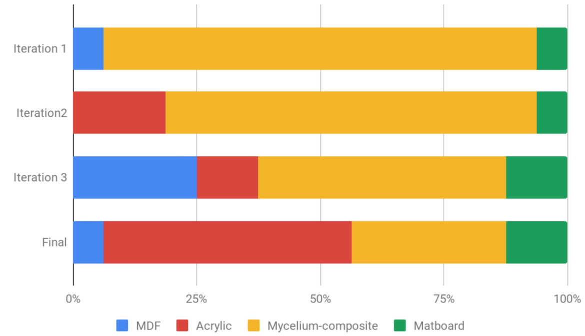

Figure 5: Materials' decision-making of participants along their prototyping process

We can see students' selection of materials in each iteration for the laser cutting exercise Fig. 5. Most participants selected mycelium composite as the prototyping material along their first stages of prototyping and changed to other materials in the final phases (high fidelity prototypes). In the first iteration of their prototype, 87.5% of the participants chose mycelium composite as a prototyping material, in the second iteration this number decreased to 75%, and acrylic appeared as a second preferred material of 18.8% of the participants. In the third iteration, only 50% of the participants chose mycelium as a prototyping material, 25% chose MDF and the other 25% of the participants chose between acrylic and matboard as their preferred prototyping material. For their final iteration, the number of participants who chose mycelium-composite to laser cut their electronic enclosure was 31.3%, and 50% chose acrylic followed by 12.5% who chose matboard instead. These are the final prototypes where design students used mycelium-composite to make part of their enclosures Fig. 9. The prototypes ranged from hollowed and rounded 3D shapes to embed a circuit playground to solid 3D molds used as a base to hold the microcontroller (circuit playground).

Reflections

The advantages participants found working with mycelium-composite were mostly related to its ecological properties as compostability and freedom in making mistakes as many times as they needed until accomplishing their desired shape and size in their design. Some students comments were:

S6: "The advantages were knowing that even if I make many mistakes and I have to laser cut again, I can put mycelium pieces in the compost bin".
S11: "The advantages of using this material is that it retains its shape after it's been laser cut. It's super lightweight too!"

Those who continued using mycelium were highly aware of the implications of using the material for sustainability, but with different levels of understanding of the environmental impact:

S17: "Mycelium-composite is a great test material that is biodegradable"
S22: "This material is easy to use and it is compostable"
S7: "I kept using mycelium-composite because it has a less ecological footprint"
S12: "I chose this material because it fulfills the purpose of prototyping, it has 90 days compost and it does not negatively impact the environment"

Some of the disadvantages the participants pointed out about mycelium-composite were related to its limitation in strength because the mycelium sheets used in the workshop were not sturdy enough as regular materials used for

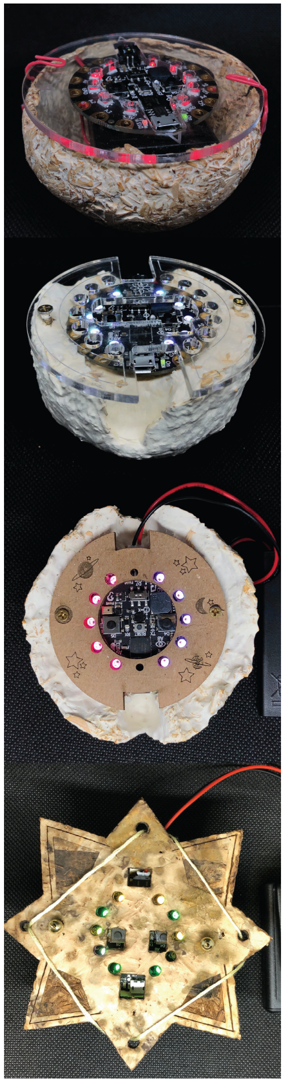

Figure 9: Novice designers' final prototypes

prototyping such as MDF or plywood. Students highlighted this limitation as one of the main disadvantages by saying:

S3: "No challenges besides the fragility of the material, but considering that it was used for 1st iteration, it was not an issue. It was going to be thrown away anyway and I used the material mostly as a starting point".
S17: "It is a bit unsteady and breaks sometimes"

We asked participants how they would see this material fit into their work and all of the participants could see this material being used in past and future projects replacing common materials used for laser cutting. Regarding 3D molding with mycelium, 95.5% of the participants agreed that they could have made past projects 3D molding mycelium.

S2: "I can see this material as a useful tool for prototyping as well as a good alternative to story foam, etc, as padding inside of components with a more durable outer shell."
S5: "I could definitely use this material to build architecture models. The precision of the laser cutter and the durability of the mycelium would be great for these types of projects because there are usually many tests to make before the final design."
S2: "I think 3D molding with mycelium can be a good alternative for preliminary drafts of 3D printed projects."
S13: "I could have created my board games by 3D molding with mycelium."
S15: "Super cool! I would do my sculpting projects with it to get that texture I can use my hardened mold."

All participants mentioned that they have benefited learning about ecological materials, not only because they know that this kind of materials exist but also it made them think about their role as designers and how to make the design field more sustainable.

S08: "It has made me think more about my footprint as a designer and piqued my interest about sustainable prototyping."
S12: "It opens up so many more possibilities for committing to sustainability while in the classroom."
S13: "I have benefited tremendously because I've opened my eyes to new materials that could change industrial design for the better."

Conclusion

This paper highlights the importance of instructors in digital fabrication to introduce to students the environmental impact of materials and techniques used for prototyping. Design students were able to make their own decisions about materials to use in their prototyping process. In order to have a more environmentally sustainable lab and class, we should be aware of the impacts of the materials in the environment such as the degradation time of materials, CO_2 emissions due to the distribution of the materials, the energy consumed from the machines while prototyping, and the disposal systems we have in our labs. There is a breakdown of energy associated with each life phase of the material and to minimize the environmental impact of prototyping we should make the right decisions about materials to prototype with and digital fabrication techniques to use.

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REFERENCES

[1] 2006. *Transmaterial*. Princeton Archit.Press. DOI: http://dx.doi.org/10.1007/1-56898-655-6

[2] R. Abhijith, Anagha Ashok, and C.R. Rejeesh. 2018. Sustainable packaging applications from mycelium to substitute polystyrene: a review. *Materials Today: Proceedings* 5, 1, Part 2 (2018), 2139 – 2145. DOI: http://dx.doi.org/https://doi.org/10.1016/j.matpr.2017.09.211 Second International Conference on Materials Science (ICMS2017) during 16-18 February, 2017.

[3] Freek V.W. Appels, Serena Camere, Maurizio Montalti, Elvin Karana, Kaspar M.B. Jansen, Jan Dijksterhuis, Pauline Krijgsheld, and Han A.B. Wsten. 2019. Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. *Materials & Design* 161 (Jan 2019), 64–71. DOI: http://dx.doi.org/10.1016/j.matdes.2018.11.027

[4] Duncan Baker-Brown. 2017. *The Re-Use Atlas*. RIBA Publishing.

[5] CHRISTINA COGDELL. 2019. Toward a Living Architecture? (Jan 2019). DOI: http://dx.doi.org/10.5749/j.ctv9b2tnw

[6] DIYbio. 2008. DIYbio. (2008). https://diybio.org/

[7] Kate Till Caroline. Franklin. 2019. *Radical Matter: rethinking materials for a sustainable future*. Thames & Hudson.

[8] Mitchell Jones, Tien Huynh, Chaitali Dekiwadia, Fugen Daver, and Sabu John. 2017. Mycelium Composites: A Review of Engineering Characteristics and Growth Kinetics. *Journal of Bionanoscience* 11, 4 (Aug 2017), 241–257. DOI: http://dx.doi.org/10.1166/jbns.2017.1440

[9] C. Lefteri. 2014. *Materials for Design*. Laurence King Publishing. https://books.google.com/books?id=g59LnwEACAAJ

[10] NaturalNews. 2018. Researchers develop blend of bioplastics that can decompose under diverse conditions. (Nov 2018). https://www.shorturl.at/fDV03

[11] Eldy S. Lazaro Vasquez and Katia Vega. 2019a. From Plastic to Biomaterials: Prototyping DIY Electronics with Mycelium. In *Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers (UbiComp/ISWC '19 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 308–311. DOI: http://dx.doi.org/10.1145/3341162.3343808

[12] Eldy S. Lazaro Vasquez and Katia Vega. 2019b. Myco-Accessories: Sustainable Wearables with Biodegradable Materials. In *Proceedings of the 23rd International Symposium on Wearable Computers (ISWC '19)*. Association for Computing Machinery, New York, NY, USA, 306–311. DOI: http://dx.doi.org/10.1145/3341163.3346938