Automated, Cost-Effective and Ecologically Conscious Shared 3D Printing via Modular Design

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***Abstract*—Our project involves the creation of a modular system for 3D printing. We take a modular approach to the design of each component of the printing pipeline, which yields improvements to cost, efficiency, safety, and scalability. Additionally, we place a focus on the use of recycled materials, both lowering the cost to operate the machinery and reducing the carbon footprint. All software and hardware will be open-source to the greatest degree possible, with a preference for permissive licenses.**

I. Introduction

Although 3D printing is starting to become accessible to consumers, it is still both expensive compared to traditional printing and requires a fairly high degree of technical knowledge beyond what is required to design the objects to be printed. With traditional printing, this was initially solved with businesses such as Kinko's™(now FedEx Office™). By sending simple documents to these companies, users could get documents printed without having to purchase and manage a printer. Unfortunately, similar services for 3D printing are expensive, environmentally wasteful, and almost always closed-source. Part of the reason for the disadvantages of existing systems is that there is relatively little automation in most existing production workflows. With our solution, most of the production pipeline is automated, from the processing of input material to the removal of parts from the print bed. Additionally, the parts are scanned for defects, and can be reprinted if any are found.

This system is especially well-suited for use in a makerspace, university, or other setting where the machines will be used communally and continually.

II. Solutions

Our design would solve these issues by creating a largely self-contained pipeline capable of accepting designs in as `.stl` files from the user through a web-based interface, queuing and scheduling prints, printing the objects, notifying the user when their print is ready, and dispensing the print to the user, all in an automated fashion, while being both economically and ecologically conscious.

The whole system can operate with minimal operator intervention, minimizing overhead. This also serves to improve safety by reducing the interactions between humans and operating equipment. The production pipeline can be run 24/7 as a result, as failures can be automatically be detected and worked around during production, with as little loss of functionality as possible. As an additional benefit, the automated system would be less likely to damage finished prints during the process of removing the print from the print bed.

To both reduce the cost and environmental footprint of the project, a plastic shredder could be added to the production process, allowing users to donate plastic (either prior prints or plastic packaging or consumer goods) in exchange for either credit on the shared printing system or for monetary reimbursement. Donated material can be sorted, cleaned, shredded, extruded, and then loaded into cartridges to be used for printing in a completely automated fashion (see Figure 3 for more details). This reduces the ecological footprint of the printer, as well as making it much cheaper – by cooperating with existing recycling services, a steady stream of high-quality post-consumer plastics can be obtained at little cost, while also promoting the printing service.

The printers integrate an automated print bed, allowing prints to be removed after completion. Final QA occurs at this time, such that prints with minor defects can be recycled and reprinted. Alternatively, the user could be prompted via text or email that the defects exist and their scale, and make the choice of whether to accept the print as-is or to reprint it. Finished prints are then stored into per-user bins, allowing users to securely pick up their prints at a time that works for them, while allowing other prints to take place in the meantime.

By structuring the project into several hardware modules, several advantages can be gained. First and foremost, splitting the project into multiple modules allows for each part to be independently verified, to ensure safety and reliability. This is analogous to the unit testing and integration testing that software uses. Simulating individual modules during the module design process also becomes much easier when we have a full specification for every module other than the one being developed, so we can treat them as black boxes.

Additionally, allowing for the composition of modules adds the potential for easy horizontal and vertical scalability for the end user. With a traditional printing setup, adding eight new printers or a plastic shredder to the input would be a major change, potentially requiring a redesign of the production line. A modular approach, on the other hand, allows for simply attaching the appropriate modules. On the software side, service autodiscovery can be used to ensure that all the modules interoperate correctly, while scalably scheduling prints from the queue.

Many of the above features would be implemented via modules as well, allowing those with smaller budgets or those who wish to pilot the program to slowly expand their production pipeline in a simple way, adding features as budget or interest allows.

III. How is it World-Changing

Realizing this concept as an open-source and fully complete project would allow for greatly increased availability of 3D printing, especially in a university setting. The ability to use post-consumer products as a source of plastic and high degree of automation greatly reduce the per-print operational costs, while the modular verification process and open-source nature of the project decrease the costs per annum. Furthermore, the high degree of scalability and queuing system makes giving access to any and all university students an attractive and realistic option, which will help to bring 3D printing to more students.

IV. Further Work

In the initial stages of this project, we will attempt to create a simple printer design with a single head. As the project matures, it is likely that we will create different printer module designs for different use cases.

One design we are working with is a printer with multiple print heads operating in the same relative positions, to produce multiple identical prints at the same time, when larger quantities are required. A concept sketch is present in Figure 5.

If the heterogeneous print modules are able to report their capabilities to the primary controller, it would be possible to intelligently schedule jobs to the printer best suited to the workload. Additionally, in the case of a defective print, another printer could be assigned to produce the print in parallel with the original. This would increase the likelihood of a successful print and allow for the system to diagnose subtler issues with a printer while still maintaining near-full throughput.

Another concept that we are exploring is automatic repair to the system, where in the case of a single module's failure, redundant modules can be ready to swap. A part change robot can then remove the defective module and add the replacement, all without human intervention.

V. Conclusion

Our approach to the 3D printing pipeline will allow for reduced cost, improved environmental friendliness, and increased accessibility of 3D printing. It also creates the potential for more robust and modular additive manufacturing equipment to exist in general, as an existing ecosystem with exacting quality standards gives strong incentive for equipment manufacturers to produce compatible products. This has been demonstrated with the Arduino™project as well as other other hardware projects in the past.

Fig. 1. Early Design Concept – Logistic Modules

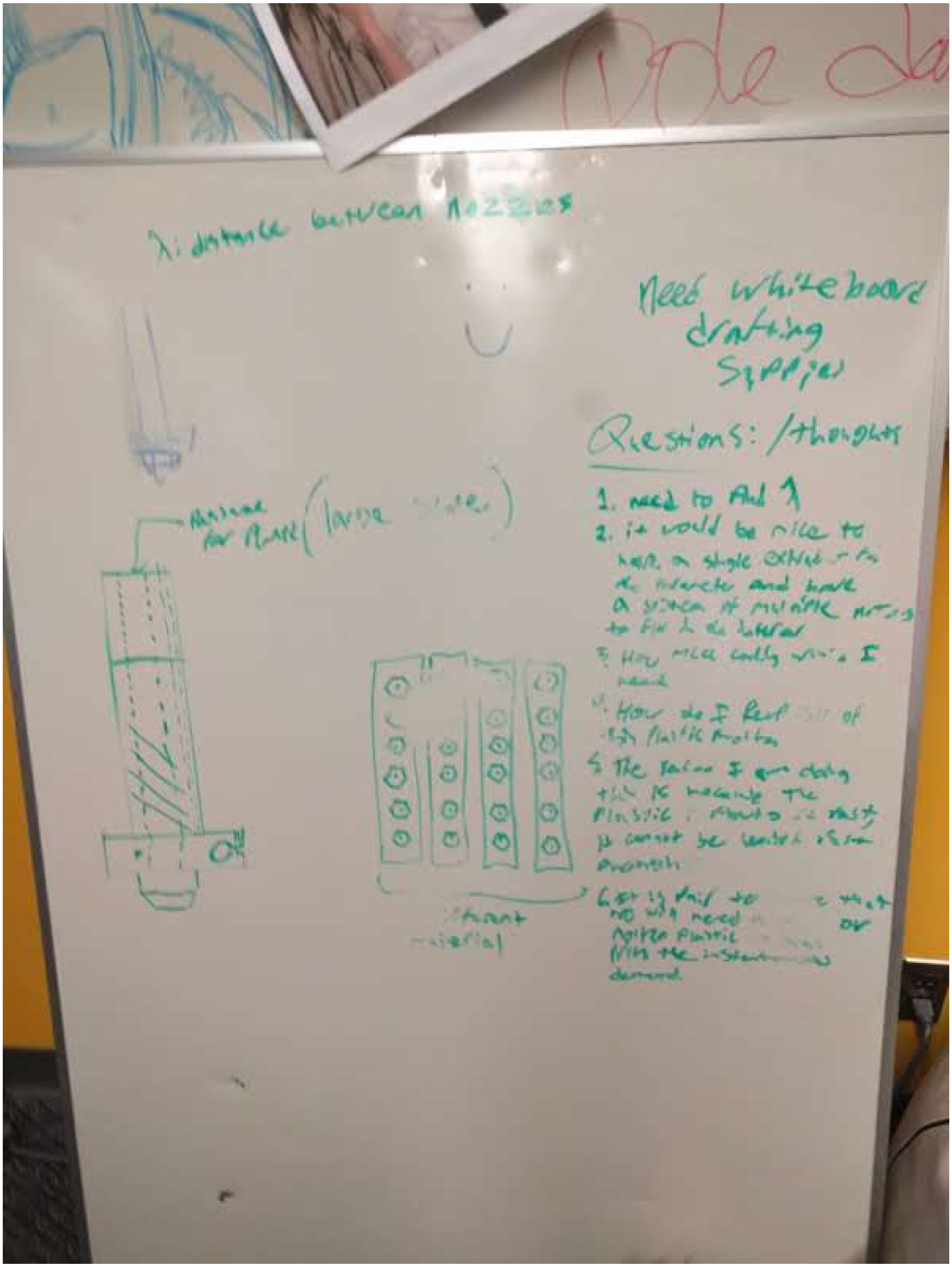

Fig. 2. Early Design Concept – Print Nozzle Arrays

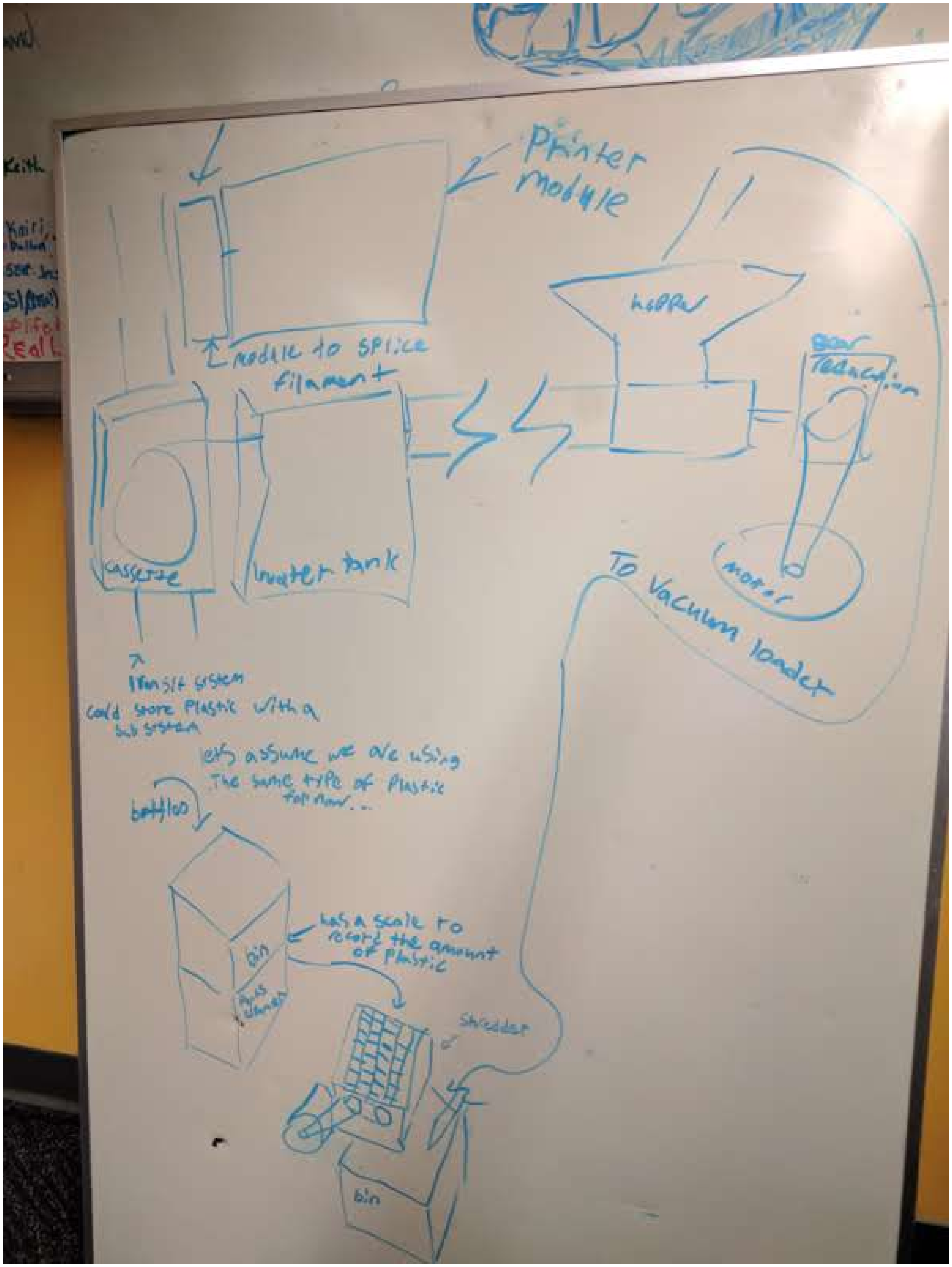

Fig. 3. Recycled Plastic, From the User to the Printer

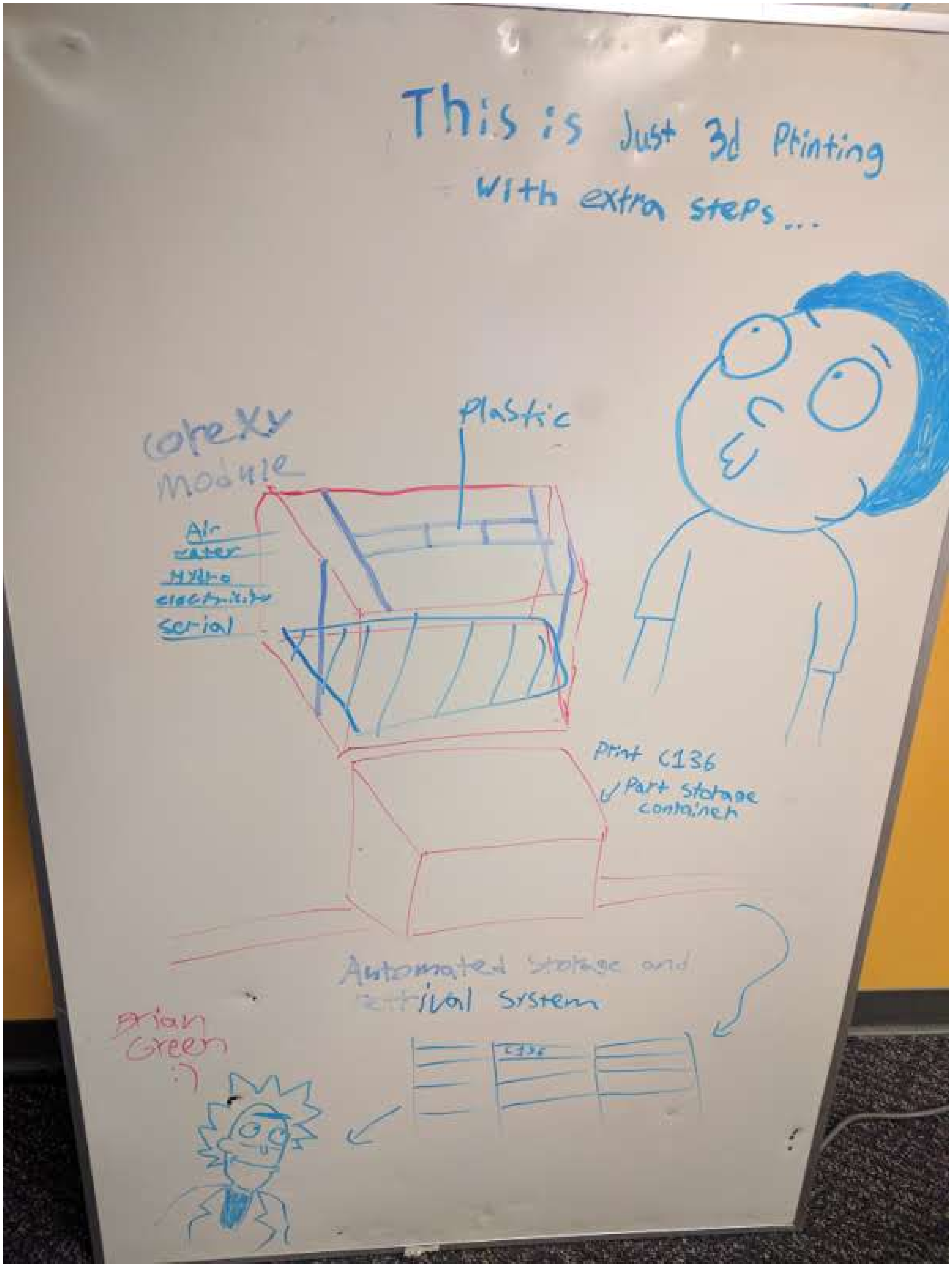

Fig. 4. Production, From Printer to Consumer

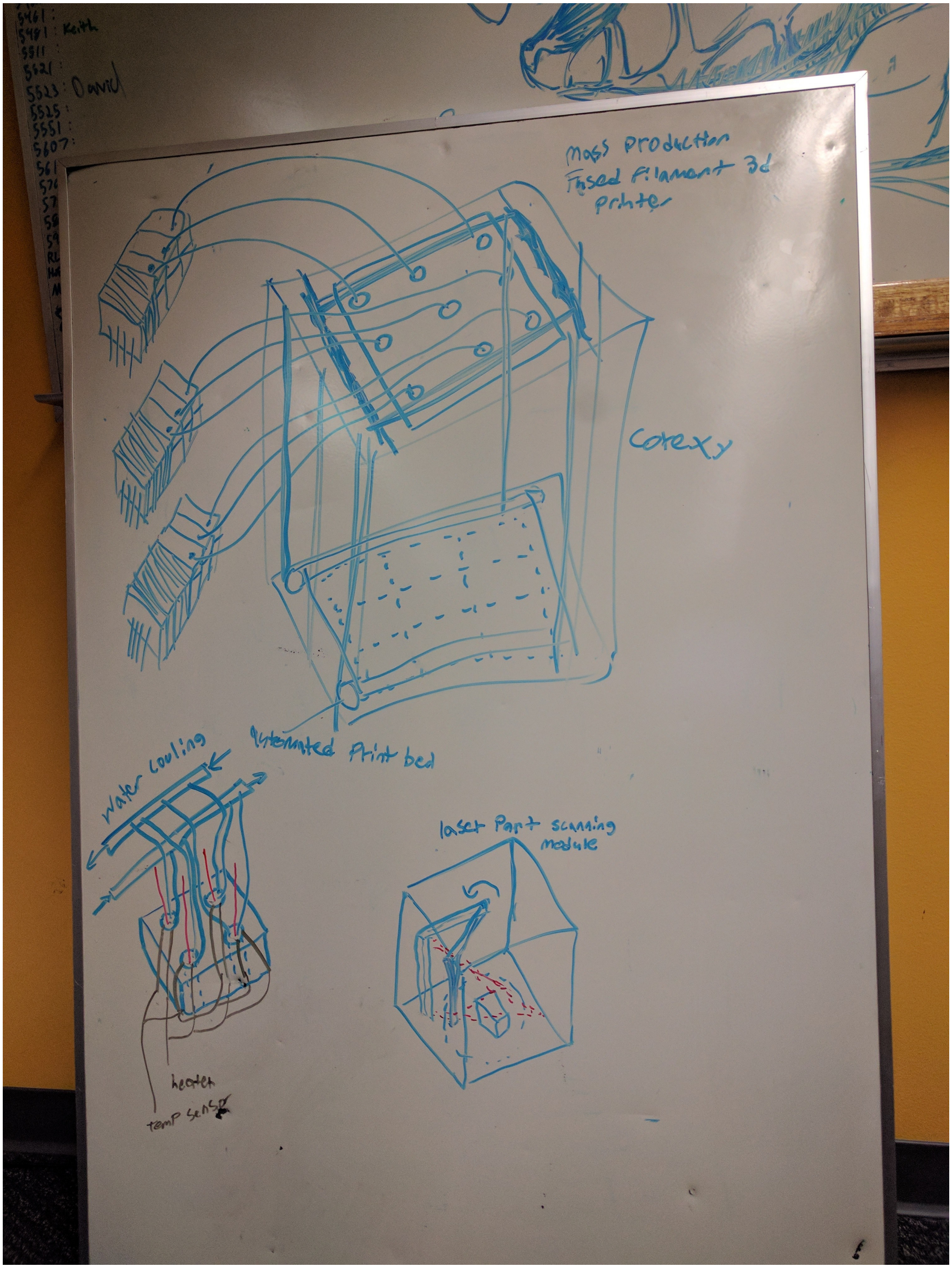

Fig. 5. Future Designs