Many Faced Robot - Design and Manufacturing of a Parametric, Modular and Open Source Robot Head

Metodi Netzev[1], Quentin Houbre[1], Eetu Airaksinen[1], Alexandre Angleraud[1] and Roel Pieters[1]

***Abstract*— Robots developed for social interaction and care show great promise as a tool to assist people. While the functionality and capability of such robots is crucial in their acceptance, the visual appearance should not be underestimated. Current designs of social robots typically can not be altered and remain the same throughout the life-cycle of the robot. Moreover, customization to different end-users is rarely taken into account and often alterations are strictly prohibited due to the closed-source designs of the manufacturer. The current trend of low-cost manufacturing (3D printing) and open-source technology, however, open up new opportunities for third parties to be involved in the design process. In this work, we propose a development platform based on FreeCAD that offers a parametric, modular and open-source design tool specifically aimed at robot heads. Designs can be generated by altering different features in the tool, which automatically reconfigures the head. In addition, we present several design approaches that can be integrated in the design to achieve different functionalities (face and skin aesthetics, component assembly), while still relying on 3D printing technology.**

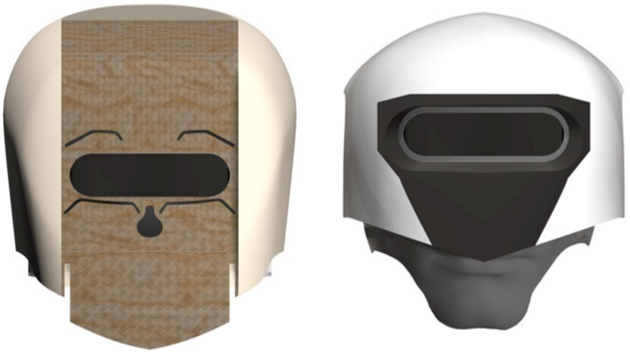


Fig. 1. Different end-users of social robots require different features and design. The designs shown here are generated by the parametric and modular development platform, proposed in this work. Left design shows a robot head with wooden facial covering. Right design shows a robot head with more humanoid characteristics. Both designs can be generated by changing parametric features within the developed FreeCAD tool.

I. INTRODUCTION

The flourishing of social robotics as a discipline and the availability of social robot platforms is caused by their potential for integration in future lives. Despite demonstrating this a multitude of times [1]–[3], with commercially available platforms ready for sale [4], robots for care remain in a research and development (R&D) stage, with field trials motivating their use. Typically however, R&D is done by engineering professionals with the majority of effort and resources focused on functional capabilities and robustness of the robot platform. While this is a necessary approach that leads to fast commercial product development, typical requirements from the end-user can not always be taken into account. In particular, such approach leads to a single fixed design of the platform where changes or small adaptations cannot be implemented and are considered as tampering [4]. However, in order to speed up field trials and increase their utilization, robots should be tailored to their specific end-user. Despite being a recommended process for any product, this is difficult to adjust after launch and is likely to require readjustment for products whose lifecycles are in their infancy [5], [6]. In the case of social robotics, such customization would imply the adaption of the platform with different aesthetics (e.g. different facial appearance, see Fig. 1) or different sensors and electronics. In a practical sense, robot suppliers could offer custom solutions for different end-users. However, with the wide range of possible user fields, any fixed catalogue is not encompassing enough. Opening the design ensures users in a low market base can modify their product without the parent company having to invest in engineering labour. This would allow for a company to increase their total market share. Circumventing these core engineering team limitations requires the robot designs to be made adaptable and modular for the end-user. The modular structure would allow the consumers to iteratively improve their robot. Each modification, being increasingly suited to the use case to improve on the practicality and the total cost of ownership. Fortunately, this is possible through current low-cost and commercial manufacturing solutions. The methodology proposed in this work addresses these core engineering limitations through engagement of the community by developing and offering an open-source tool that provides a robot head as a template whose modification towards the requirements and needs of the user is encouraged.

Similar approaches towards open design have garnered interest in fields other than robotics [6], [7]. Meanwhile, open source robot development platforms have shown to increase availability of project components for researchers, industry and hobbyists [8]. As the focus of this paper is the physical design and overall system architecture of an open source robot head platform, its presentation within the context of new product development helps users with identifying constraints and further editing the model. Functionality is formed according to research criteria from the particular fields of interest (e.g. Human Robot-Interaction, Artificial Intelligence and a practical need for independent and low

---

[1] Department of Automation Technology and Mechanical Engineering, Cognitive Robotics, Tampere University, 33720, Tampere, Finland; `firstname.surname@tuni.fi`

cost Numerically Controlled manufacturing).

The difference between open source and commercial robots is that intellectual property is attempted to be disseminated. For example, the structural and visual hardware of robots such as Pepper and Nao is not provided on Softbank websites for modification and reproduction [4]. The implication of this is the inability of users to amend a robot feature in the absence of parts for the region they work in. For this purpose an openness in design is prioritized. This helps users identify their use cases, and improvements with which the robot head can suit their projects. In the case of social robotics, similar work is that of Vandevelde, et al., with their design of OPSORO [9], OTO [10] and Probo [11].

Other major work in this area is the iCub humanoid robot [12], designed to investigate the more complete cognitive aspects of manipulation, its head and torso movements are increased to 6 Degrees of Freedom (DOF) [12], [13]. This complexity, associated with the use of metals and the safety precautions due to metal manufacturing increases the price. A less complicated approach could be utilised for cognitive models of lower complexity, not requiring interdependence of all robot limbs. Fully satisfying such interaction criteria, the Gummi Arm [14] is chosen as the basis for its manipulation capabilities and safety in interaction. As with the Gummi Arm, the load carrying structure strength is not a priority and can therefore be manufactured using 3D printing polymers.

The capability to create a functional anthropomorphic robot using 3D printing are demonstrated by InMoov [15]. Despite not being described in the documentation, the head of this robot comes with 2 degrees of freedom in the neck, making it equal in functionality to our design in terms of directing the sensors. The difference is in the design files being created as a dimensionally lossy mesh file format. While it lays out important structural and conceptual functionality with the capability to edit modules in Open Source Software, its parts are more difficult to edit and relations in assemblies are not maintained with dimensional changes.

According to Komatsu and Kamide [16], social robot features need to be suited to the role they fulfill for the user to trust their output. In the process, they have identified variations in facial feature arrangement to suit tasks such as entertainment, education, guidance, assistance and medical care. The difficult to edit meshes used to create InMoov can therefore be a hindrance to testing the aesthetic embodiment of the robot for suitability [15]. Similarly, there are problems of scalability in practical applications where parts of the platform need to be edited in size while the functional electronic modules remain the same. For example, internal sound damping may require a larger head cavity while retaining audio-visual sensor attachment spacing.

Within embodiment studies such as those by DiSalvo [17], [18] the majority of components are tested through mock-ups and not production ready designs. This problem is identified in the design recommendations made by the authors. Stating that to assess features such as the nose, mouth and eyebrows, a skin should cover the internal structures of the robot, giving a production ready look. Despite the availability of their test reconfigurable robot, Pearl, designs have not been publicly released for modification. A solution is partially offered by Desai et al. [8], where an assembly optimisation technique can arrange parts within an enclosure to comply with assembly rules. Unfortunately, this method only covers the attachment of printed circuit boards (PCB) and basic sensors. This method does not offer the possibility to integrate custom interfaces for each part as it is a prototype.

The robot head proposed here, MaFaRo for Many Faced Robot, emphasizes replicability, customisability and mobility of the entire head assembly. Compared to other robot head designs it is scalable in absolute dimensions and in terms of individual parts within the assembly. This flexibility is an improvement over InMoov while retaining the manufacturing cost advantage over iCub, Pepper and Nao. Similarly to iCub, its open source design allows modification for early adopters contrasting with the closed designs of Pepper and the modular Pearl. Unlike the iCub, it is not tested to support the simultaneous actions of multiple limbs, a concern stemming from the softness of the frame, shared with the Gummi Arm. Despite this, the softness is associated with safety in operation with humans and customisability. These concepts are used in the creation of the OPSORO, OTO and Probo. MaFaRo, builds on the architecture of these robots through allowing movement in the neck.

In this work, we present developments towards an open-source, parametric and modular robot head, a winner of second prize in the Hardware design competition of the International Conference on Social Robotics, Qingdao, China, in November 2018. Overall, we make the following contributions:

- Parametric and modular design approach for humanoid robot heads
- Adaptable and scalable assembly and monocoque
- Functional design concepts for low-cost manufacturing
- Discussion on the challenges in open and modular design and recommendations for solution.
- Interface suggestions for electronic components used in cognitive robotics

We continue this paper with the Design Requirements in Section II and the Design Approach in Section III. Results and Discussion is presented in Section IV and Section V, respectively. Finally, we conclude in Section VI.

II. DESIGN REQUIREMENTS

The design is driven by the engineering requirements, stakeholders and users in the project. For example, AI researcher needs include the capability to find and manipulate objects in the real world, therefore requiring the physical capability of the head to look around [12]. HRI researchers need to hot-swap the looks of the robot if physical models are used. For example, 12 variations of robot heads have been tested in [18]. The user community and hobbyists require a flexible model to accommodate differences in electronic equipment and a simplified manufacturing approach. These needs are integrated to work together through engineering considerations such as selecting interface types and tolerances. Following, we discuss several requirements that a design should take into account.

A. Functionality

Functionality determines what purpose the robot head is capable of serving. The primary functions are to serve as a sensory cluster unobstructed by the manipulator arms. It should provide the necessary sensory information for experimentation in human-robot interaction research and thus act as interface towards people. Additional functionality can, for example, be enabled by integration of the MaFaRo head with the Gummi Arm [14].

B. Manufacturing

Manufacturability is oriented towards commercially available 3D printers. Tasks and details should be enabled such that manufacturing can be replicated by researchers and hobbyists not trained to use these machines. Availability of numerical control, and the automation of manufacturing machine instructions through slicer software, cheap Fused Deposition Modelling filament enable the manufacturing method. It is preferred to laser cutting because it can manufacture 2D and 3D objects with a lower complexity machine and a smaller workshop-floor print [19]. Documentation, durability testing, availability of standard components, as well as support through the community and an open source architecture are considerations when choosing a printer. The time needed to troubleshoot during long prints can hence be reduced.

C. Flexibility

Flexibility requirements accommodate researchers requiring a structural base and visual customization. This is enabled through FreeCAD [20]. Parametrically controlled modelling is partially connected through a spreadsheet allowing modification of camera cut-out and holder dimensions at the same time. In HRI, it allows the adjustment of the eye module width. Accurate results are required during manipulation of the models. Regardless of the size of the eye hole, it must maintain its roundness. In the case the model is changed using a mesh editor for a subsequent enlargement of the eye hole, the discretisation induced may make the model difficult to scale upwards. Similarly, electronic components such as audio piezo sensors should be accommodated in the ear module through PCB mounting holes. This owes to their predictable locations and mounting orientation, and can be replaced by sheet metal or plastic. Compatibility with previous platforms is similarly possible through the spreadsheet and its ability to reference outside components.

D. Implementation goal

Implementation goals are centred around adoption by international researchers and hobbyists. This market segment includes innovators and early adopters. These users require a compelling competitive advantage in order to use a product, but are willing to troubleshoot as long as benefits outweigh costs. Their goals are centred around investigative work of variations in robotics [5]. The robot head should primarily support these activities with a manufacturing goal of mass customisation to suit local product availability of fasteners for example [21]. This should guarantee the lowest possible price and hence be unhindered by manufacturer lock-in. If users are available, the feedback, should determine which parts should be standardised and produced on larger scale. Development of technical knowledge is encouraged through documentation. Making the assembly techniques easier to grasp when the head is being customised for home automation or while it is being used as a puzzle for children.

E. Usability

Usability of the head is geared towards speed of operation without sacrificing functionality. The comfort features should be balanced between manufacturing, assembly and hot-swapping capability ease. In the process, the tool amount is kept to a minimum. A circumvented problem is lowered likelihood of being unable to fit the tools into tight spaces. For example, a set-up could allow an average sized human to exchange the components inside the skull. Variations in HRI parameters on the other hand can be based on visual modifications. Changeover of the visual surface should then be made possible through as few parts as possible. As such, HRI researchers should be able to switch between two different looks of the robot in the timeframe of two minutes. As the majority of the value of the model lies in it being editable, it must be available through an open source design.

F. Practical considerations

The practical considerations take into account manufacturing and operation of the head. For example, tolerancing could affect the tightness of the ear attachment module which should prevent sound leakage. Likewise, the tolerancing should be adaptable to accommodate 3D printing with a smaller diameter nozzle or a material like Polypropylene.

The previously mentioned projects and trends affect the robot head design mutualistically. For example, electric motors from ROBOTIS are already selected and tested in projects such as Poppy [22]. Their reinforced polymer and structurally strong casing allows them to be used as structural elements. As the manufacturer provides 3D CAD models, these motors can be used as mounting mechanism. Having an open source, structural platform for housing sensors and expressiveness on the other hand can simplify the implementation of facial expression, as compared to, for example, OPSORO.

III. DESIGN APPROACH

Based on the requirements of the head design discussed in the previous section, the approach taken for the MaFaRo head is presented as follows. In particular, details are given towards the modelling of a head and the integrated functional design concept.

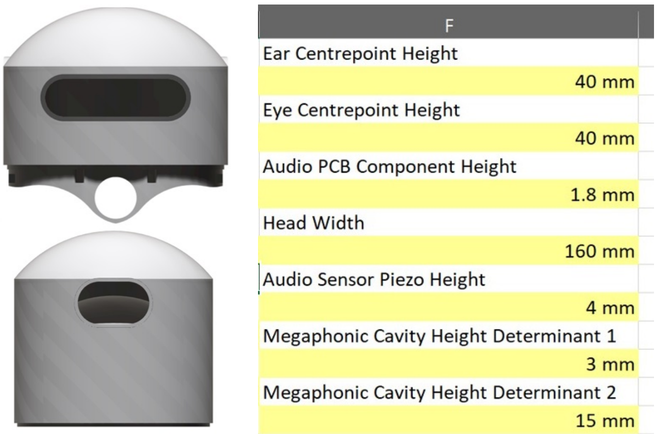
A. Parametric modelling

Modularity is used in conjunction with parametric modelling. Alongside components adapting in context of each other, a numeric linkage to external files is also possible. In FreeCAD this functionality is accessible through Python and a Spreadsheet (See Fig. 2). For users unfamiliar with programming, the spreadsheet allows a familiar interface. It is accessible through the internal feature tree and allows cell headings and names to be assigned and linked. Despite this, the functionality remains in its infancy whereby no figures can be inserted to graphically demonstrate the effects of the parameters.

B. Functional design concepts for low-cost manufacturing

Low-cost manufacturing has limitations towards aesthetic design due to the vertical resolution of 3D printing and the properties of the printing material. For example, the printing resolution is noticeable by touch and materials can warp and shift due to temperature differences. Instead of avoiding such issues with light based printing machines (e.g. selective laser sintering), the approach here offers other materials to be integrated in the design. This allows the printed parts to be used as shell structures. In the robot head design other functional designs concepts are the following (see Fig. 3 and Fig. 4)

- **face/skin aesthetic through laser cutting** - As curved shapes with patterns can be problematic for 3D printing, the frontal face of the robot head is replaced by a flexible wooden sheet. Flexibility of the wooden panel is achieved by laser cutting a repeating pattern in the design. Different patterns can achieve a different look and provide a desired flexibility. Similarly, the structural 3D printed shell can be manipulated to accommodate a flexible screen to display expressions or other feedback.
- **Magnetic assembly** - Plug and play integration of sensors and electronics should not be hindered by the complexity of assembly. This means a robot head should be easily opened and closed without the need of extra parts and tools for fastening (e.g. screws and bolts). Moreover, as traditional assembly techniques might not be 3D print friendly (screws and bolts require inserts or washers to suit the plastic/polymer material), a magnetic assembly concept avoids such difficulties. In detail, different face parts are designed with recessed cavities in which magnets are glued. Complementary parts are then held together by magnet pairs. This fastening technique is recommended when the required pull-out force is low.
- **Pluggable screw adapters** - A second assembly technique where 3D printing can benefit with design complexity is the integration of parts by screw threads. Instead of connecting sensors and electronics directly to the head or body of a robot, which is often difficult to access, these are fixed to an interchangeable adapter. Such adapter can be screwed inside the head without needing delicate fixtures. In detail, an ear attachment adapter is designed that holds a microphone, on either side of the head.
- **Shell structure** - Audio sensors and camera are located inside of the skull monocoque, a 3D printed shell. It is used to isolate the audio sensors from each other. its thickness can be varied depending on the finish required and materials available. Using an internal structure ensures basic functionality levels are met with whatever the external facade structures look like.



F
Ear Centrepoint Height
40 mm
Eye Centrepoint Height
40 mm
Audio PCB Component Height
1.8 mm
Head Width
160 mm
Audio Sensor Piezo Height
4 mm
Megaphonic Cavity Height Determinant 1
3 mm
Megaphonic Cavity Height Determinant 2
15 mm

Fig. 2. On the left rendered designs demonstrating the parametric adaptability. This demonstrates the different height and camera parameters while maintaining the same base skull for support and functionality. On the right a cut-out of the spreadsheet for changing head design parameters.

IV. RESULTS

Satisfying the design criteria is done through grouping and assigning a design strategy to each group. The overall process utilises a combination of top-down design to provide an appearance and bottom-up design to modify parts such as the camera holder or the base of the neck to accommodate the electric motor and structurally connect it to the rest of the parts. The result being a model capable of reorganising and maintaining relations amongst the functional modules when HRI dimensions (i.e. common head dimensions) are edited. The final design is the result of the fulfillment of the requirements through the following design methodologies.

A. Subframe architecture

The subframe is a monocoque serving as a skull to which external parts can be fitted. The module dimensions, outer shape and inner part locations can be altered depending on the desired look and chosen electronic components. When changing parameters, the global design is automatically updated to comply with the constraints within sketches. The majority of the leading features and designs originate from three main sketches (located on the three Cartesian planes). For example, changing the width of the head, automatically adapts the mounting base and its magnet mounting recesses (see also Fig. 2). The skull is attached to two servos at the base or neck to achieve pitch and yaw motion.

The monocoque is designed to accommodate externally mountable parts that can be attached to enable non-sensory

Fig. 3. Design approach of the Many Faced Robot (MaFaRo) aimed towards a cyborg-look. Left image shows an exploded view of all internal and external parts of the robot head. Middle and right image shows a rendered view of the exploded view. The design uses the same base skull as template for external parts that serve for aesthetics and sensor integration.

functionality and aesthetic enhancements. These include the top panel (helmet), front panel (face) and mouth. Environmentally interactive components such as the camera insert, ear attachment and speaker housings are mounted internally to the skull. Both of these parts are explained in the following section.

B. *Panels and covers*

As proof of concept to demonstrate the prospects of this design approach, two directions are taken towards social robot design (see Fig. 1). These are 1. a friendly human-like robot head design (See Fig. 5) and 2. a cyborg-like robot head design (See Fig. 6). The human-friendly design includes a wooden panel with a laser-cut repetitive pattern, adding flexibility and aesthetics, and basic facial features to achieve a human-friendly look (e.g. eyebrows, nose) without giving much of a hint on the cognitive capability of the robot. The wooden, aesthetic panel is glued on a 3D printed backing panel, printed in the right shape. The top structure is held in place through friction with the skull and the bottom is held by a magnetic assembly. Ears are screwed from the exterior into the sensor adapters described earlier. The cyborg-like design includes a helmet that can be slid over the skull, and a mouth (scanned from a real human) that is attached through a magnetic assembly.

C. *Sensor integration*

In both robot skull designs presented above, the same sensor features are present, however their locations and dimensions are different to demonstrate the flexibility of the design tool. The sensors are a standard camera (Intel Realsense D435) and two microphone sensors (Sparkfun SEN-12642) in the ears. Both sensors are fixed to a holder which is fitted into the robot head by utilizing the functional design concepts presented in this work. In particular, the ears are fitted by pluggable screw adapters and the the camera is fixed by an insert.

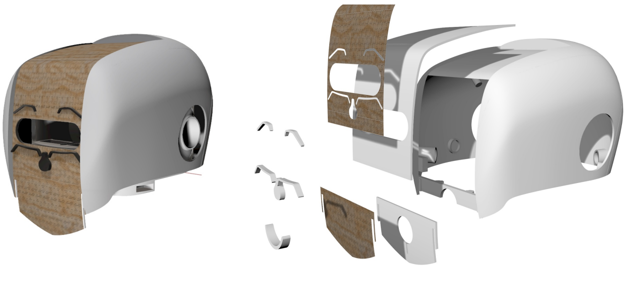


Fig. 4. Design approach of the Many Faced Robot (MaFaRo) aimed towards a friendly look. Right image shows an exploded view of all internal and external parts of the robot head. The design uses the same base skull as template for external parts that serve for aesthetics and sensor integration.

D. *Open-source design*

The developments in this work are available open-source for the robotics community in the GitHub repository[1]. FreeCAD[2] is used for design on a standard Desktop PC without the need for professional computer hardware acceleration (no double floating point precision necessary). For manufacturing we utilized a Prusa i3 MK3[3] with Slic3r[4] software for 3D printing and a Epilog FusionPro for laser cutting. Materials used where standard Polylactic Acid (PLA) and plywood. Our developments build upon the open-source GummiArm project [14] and is therefore compatible with ROS and other open-source standards for robotics research (e.g., OpenCV). A video demonstrating the designs in action is provided here: https://youtu.be/2lJgnSlbGh0.

V. DISCUSSION

The developments presented in this work aim to lower the entry barrier for social scientists and roboticists active in the field of human-robot interaction. At the same time, other participants in related fields and including non-professionals can benefit from the open-source tools. To achieve this, effort

[1] `https://github.com/CognitiveRoboticsTUT/MaFaRo`
[2] `https://www.freecadweb.org`
[3] `https://www.prusa3d.com/original-prusa-i3-mk3/`
[4] `https://www.prusa3d.com/slic3r-prusa-edition/`

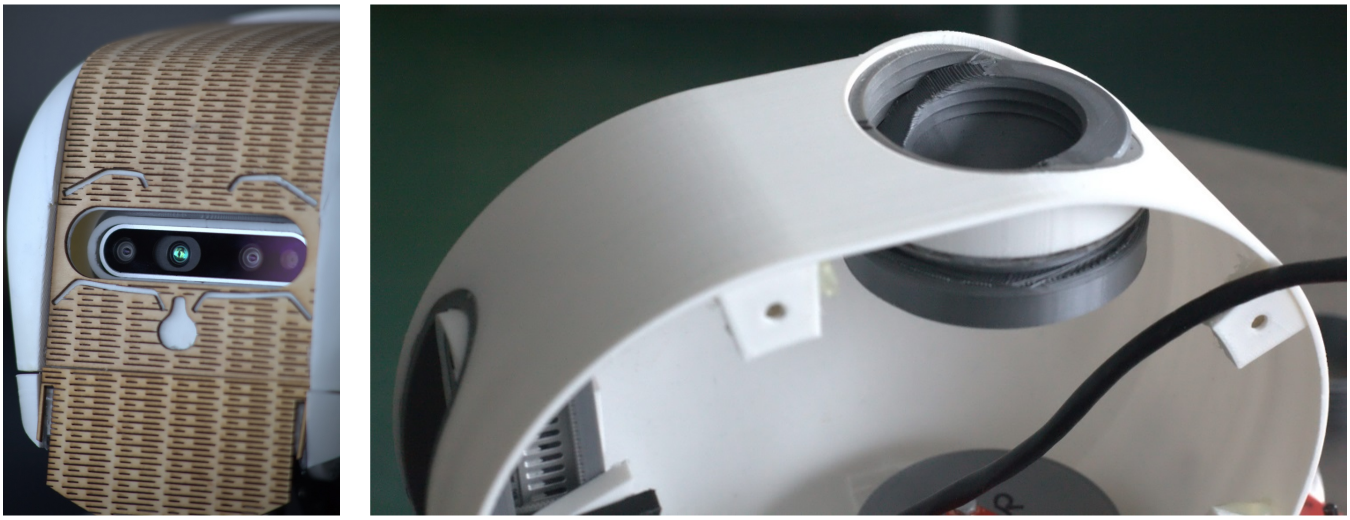


Fig. 5. Resulting designs of the parametric robot head. On the left a close-up image is shown of the wooden face structure with patterned flexibility, aimed towards a friendly look. On the right a close-up image is shown of the magnetic assembly points (white squares with holes) and the pluggable screw adapter for the microphone (grey). For a video, see https://youtu.be/2lJgnSlbGh0

Fig. 6. Resulting design of aesthetic facade demonstrating a bionic look through 3D scanned data and its manipulation.

has been been put towards making the skull FreeCAD model adjustable, and generic to accommodate multiple use-cases. Unfortunately, the early stages of FreeCAD development can be unstable, yield unpredictable failures and results. The work can be done in a third of the time with industry standard software such as Catia, SolidWorks and Inventor. This owes to primarily working around limitations of being able to reference geometry from other features within an assembly or parts. Implementation of top-down design and bottom-up approaches increase model rebuild times. Editing parts, higher in the design tree take can take more than 2 minutes especially when using the spreadsheet. Open-source and free means support and compatibility from the community offers a large quantity of useful plug-ins, even if they are buggy. Despite this, plug-and-play functionality for add-ins is present to add further refinement. Editing the assembly parts of the head assembly out of context of the assembly file is also manageable by beginner designers through the export functions. Nevertheless, the ability of interested partners to contribute and improve the designs, suggest changes and additions would be useful and create value with the work and for the community. This has been proven by other projects such as iCub and ROS, and is encouraged for MaFaRo as well.

In addition, a more technical discussion on the design approach and its properties is given as follows. Electromagnetic interference should be avoided by relocation of attachment magnets in case magnetic microphones are used. This is enabled in the model through the top sketch where the front or rear pairs of magnets can be moved towards the back or front of the printed skull. Similarly, wire routing should have multiple exit points at locations they cannot be seen or interfere with the rest of the assembly. These can be made by hand after the base of the head is printed and mounted as it is easier to remove material than add it. Cooling is required wherever components calculate or build a representation of their visual environment. Due to the frequently used ASICs on mapping cameras and heatsink chassis, the bodies of these devices have to dissipate up to 2.85W, keeping the silicon based components operating at 50 Degrees Celsius (C) with brief temperature bursts of 70 (C) maximum. This requires leaving the passive cooling openings on the camera unobstructed and with sufficient skull space.

VI. CONCLUSION

Current trends in low-cost manufacturing enable the customization of social robots to different end-users. In this work we have proposed a parametric, modular and open-source design tool based on FreeCAD to allow changing robot head designs and aesthetics on the fly. The design is aimed for low-cost manufacturing and rapid prototyping (3D printing and laser cutting). Additionally, design concepts are presented to circumvent the disadvantages of these manufacturing methods. These are 1. material flexibility by patterned laser cutting, 2. magnetic assembly for accessibility, reduced material fatigue and 3. pluggable screw adapters for tight sensor integration. Two robot head designs are presented demonstrating aesthetic possibilities in terms of friendliness and technical approach. These heads demo the potential for HRI researchers to use the parametric skull as basis for creating further designs without the need to worry about sensory functionality. The experimental nature of the used tools such as FreeCAD, however, ind All our work is provided as open-source to the robotics community to motivate potential users to adopt our approach.

REFERENCES

[1] R. Gockley, A. Bruce, J. Forlizzi, M. Michalowski, A. Mundell, S. Rosenthal, B. Sellner, R. Simmons, K. Snipes, A. C. Schultz, *et al.*, "Designing robots for long-term social interaction," in *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. IEEE, 2005, pp. 1338–1343.

[2] I. Leite, C. Martinho, and A. Paiva, "Social Robots for Long-Term Interaction: A Survey," *International Journal of Social Robotics*, vol. 5, no. 2, pp. 291–308, Apr. 2013.

[3] D. Fischinger, P. Einramhof, K. Papoutsakis, W. Wohlkinger, P. Mayer, P. Panek, S. Hofmann, T. Koertner, A. Weiss, A. Argyros, and M. Vincze, "Hobbit, a care robot supporting independent living at home: First prototype and lessons learned," *Robotics and Autonomous Systems*, vol. 75, pp. 60–78, Jan. 2016.

[4] "Pepper, SoftBank Robotics, note = https://www.softbankrobotics.com/emea/en/pepper, accessed: 2019-02-17," 2018.

[5] E. M. Rogers, *Diffusion of innovations*. Simon and Schuster, 2010.

[6] R. G. Cooper, *Winning at new products: Creating value through innovation*. Basic Books, 2011.

[7] W. Lidwell, K. Holden, and J. Butler, *Universal principles of design, revised and updated: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Rockport Pub, 2010.

[8] R. Desai, J. McCann, and S. Coros, "Assembly-aware design of printable electromechanical devices," in *The 31st Annual ACM Symposium on User Interface Software and Technology*. ACM, 2018, pp. 457–472.

[9] C. Vandevelde, F. Wyffels, B. Vanderborght, and J. Saldien, "An open-source hardware platform to encourage innovation," *IEEE Robotics & Automation Magazine*, vol. 1070, no. 9932/17, p. 2, 2017.

[10] T. Vervisch, N. Doms, S. Descamps, C. Vandevelde, S. Verstockt, J. Saldien, *et al.*, "Oto–a diy platform for mobile social robots in education," in *International Conference on Robotics and Education RiE 2017*. Springer, 2017, pp. 257–262.

[11] A. De Beir and B. Vanderborght, "Evolutionary method for robot morphology: case study of social robot probo," in *Human-Robot Interaction (HRI), 2016 11th ACM/IEEE International Conference on*. IEEE, 2016, pp. 609–610.

[12] G. Metta, L. Natale, F. Nori, G. Sandini, D. Vernon, L. Fadiga, C. Von Hofsten, K. Rosander, M. Lopes, J. Santos-Victor, *et al.*, "The icub humanoid robot: An open-systems platform for research in cognitive development," *Neural Networks*, vol. 23, no. 8-9, pp. 1125–1134, 2010.

[13] A. Parmiggiani, M. Maggiali, L. Natale, F. Nori, A. Schmitz, N. Tsagarakis, J. S. Victor, F. Becchi, G. Sandini, and G. Metta, "The design of the icub humanoid robot," *International journal of humanoid robotics*, vol. 9, no. 04, p. 1250027, 2012.

[14] M. F. Stoelen, F. Bonsignorio, and A. Cangelosi, "Co-exploring actuator antagonism and bio-inspired control in a printable robot arm," in *International Conference on Simulation of Adaptive Behavior*. Springer, 2016, pp. 244–255.

[15] G. Langevin, "Inmoov-open source 3d printed life-size robot," 2014, http://inmoov.fr, Last accessed on 2019-02-17.

[16] T. Komatsu and M. Kamide, "Designing robot faces suited to specific tasks that these robots are good at," in *Robot and Human Interactive Communication (RO-MAN), 2017 26th IEEE International Symposium on*. IEEE, 2017, pp. 1–5.

[17] C. F. DiSalvo, F. Gemperle, J. Forlizzi, and S. Kiesler, "All robots are not created equal: the design and perception of humanoid robot heads," in *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques*. ACM, 2002, pp. 321–326.

[18] J. Goetz, S. Kiesler, and A. Powers, "Matching robot appearance and behavior to tasks to improve human-robot cooperation," in *The 12th IEEE International Workshop on Robot and Human Interactive Communication, 2003. Proceedings. ROMAN 2003.* Ieee, 2003, pp. 55–60.

[19] E. Oberg, F. D. Jones, H. L. Horton, H. H. Ryffel, and J. H. Geronimo, *Machinery's handbook*. Industrial Press New York, 2004, vol. 200.

[20] F. Organisation, "Freecad: Your own parametric modeler," 2019, http: www.freecad.org, Last accessed on 2019-02-17.

[21] B. J. Pine II and R. Hull, *Mass customization: the new frontier in business competition*. Harvard Business School Press, 1995, vol. 288.

[22] M. Lapeyre, P. Rouanet, and P.-Y. Oudeyer, "The poppy humanoid robot: Leg design for biped locomotion," in *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 2013, pp. 349–356.