NEW MEDIA ART, DESIGN, AND THE ARDUINO MICROCONTROLLER: A MALLEABLE TOOL

by

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A thesis
submitted in partial fulfillment
of the requirements for
the degree of Master of Science
(Theory, Criticism and History of Art, Design and Architecture)
Within the joint degree M.L.I.S. program
School of Art and Design
Pratt Institute

February 2010

Acknowledgements

Thank you to a great number of people who helped along the way.
Dr. David Walczyk, advisor
Dr. Ed Decarbo, History of Art & Design Department Chair
Dr. David A. Shamma
Melinda Caric
Eric Skiff
Eric Beug
Nick Farr
Tom Igoe
Jeffrey Barke
Max Whitney
Clive Thompson
Phillip Torrone
NYC Resistor
Bug Labs
Gian Pablo, for my first Arduino lesson
And of course, Mom and Daggles

Thank you to all who participated in my interviews:
Paola Antonelli, Hernando Barragán, John Bennett, Dr. Julian Bleeker, Dr. Jan Borchers, Jennifer Bove, Dr. Leah Buechley, Dario Buzzini, Alexandra Deschamps-Sonsino, Rob Faludi, Limor Fried, HC Gilje, Dana Gordon, Dr. Mark Gross, Usman Haque, Kate Hartman, Dr. Björn Hartmann, Jeff Hoefs, Younghui Kim, Edith Kollath, Josh Kopel, Mike Kuniavsky, Tod Kurt, Dr. Jean-Baptiste Labrune, David Mellis, Eric Pan, Douglas Repetto, James Seawright, Rebecca Stern, Peter Terezakis, Dave Vondle, Fabian Winkler, Nicholas Zambetti, David Zicarelli

Thank you to the Pratt Institute Library and the History of Art & Design Department for allowing me to publish my thesis under the creative commons license.

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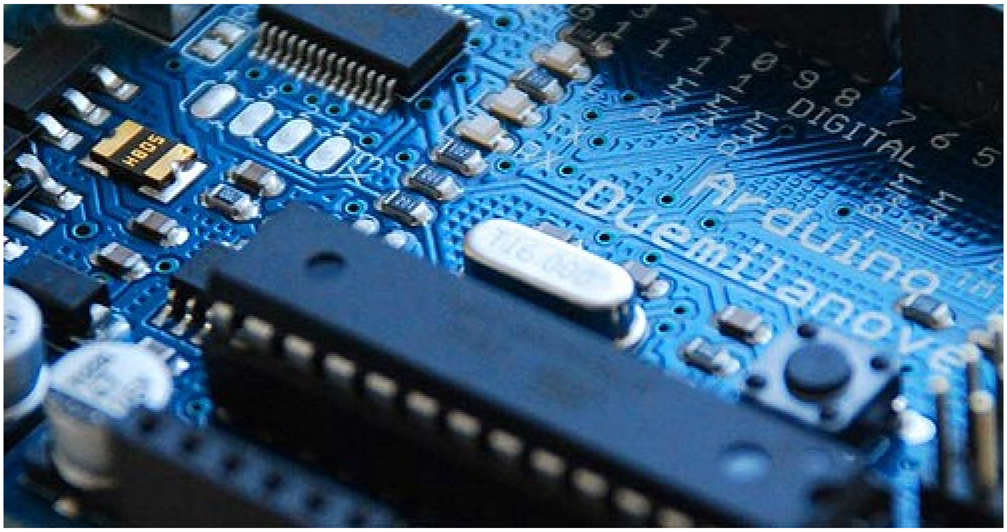

1 *The Arduino Duemilanove*, 2008, (Photograph provided by Anthony Mattox)

1. Introduction

The Arduino microcontroller[1] is used in art and design as an open source programmable tool to create interactive works. It can drive motors, LEDs, sensors and other components. Microcontrollers are small computing systems used for low power and low memory purposes. A microcontroller consists of a microchip on a circuit board with read-write capabilities, memory, inputs and outputs. The Arduino microcontroller adheres to these capabilities and a close-up is pictured in Fig 1, the entire microcontroller can be viewed in Fig 3. While microcontrollers have had a presence in the arts for decades, the Arduino microcontroller is among the first microcontrollers specifically designed for artists and designers. The Arduino microcontroller allows artists and designers to execute electronic-incorporated works without knowing the internals of the hardware or software. Artists and designers have been influential in the evolution of the Arduino

[1] Arduino. http://arduino.cc/

microcontroller since its birth. Thirty-seven Arduino experts and community members were interviewed. A list of interviewees is included in Section 3.2.

Three relationships surrounding the Arduino microcontroller were explored through the lens of new media art and design. One relationship studies the semantics, or how the Arduino was used and the associated experiences of the participant. The second relationship involved art and design as a catalyst for modifications to the Arduino platform. And third, the relationship of the Arduino microcontroller's ease of use which allowed artists and designers to devote their time and energy to the creative process. After examining the first relationship, how the Arduino microcontroller was being used in art and design, two discoveries were formulated. The discoveries confirmed the hypotheses of the second and third relationships. The most prominent discovery was that both the form and the function in art and design pieces were catalysts in modifying the Arduino microcontroller. A subsidiary discovery was that while the Arduino microcontroller assisted in creativity, the technology was not creating the art.

The design of the Arduino microcontroller caters to a non-technical audience[2] by focusing on usability[3] to achieve its intended goal as a platform for designers and artists. The Arduino microcontroller gives artists and designers the ability to use and modify computational hardware easily and inexpensively. Changes which affect the Arduino's evolution arise as a benefit of open source hardware and software. The advantage of the open source initiative is the ability to freely change attributes and configurations to discover how the program might be affected and learn from it. The Arduino

[2] However, this thesis is written for a technical audience with an interest in the history of art and design.
[3] According to usability expert, Jakob Nielsen, "Usability is a quality attribute that assesses how easy user interfaces are to use". http://www.useit.com/alertbox/20030825.html

microcontroller itself is based on other open source tools for artists. The most influential to the Arduino are the Processing[4] language and the Wiring[5] microcontroller. Processing is a Java based visual language for artists, and the Wiring microcontroller is an input/output[6] board for arts, media and education. Due to new tools such as these and the Arduino microcontroller, artists and designers are capable of completing tasks traditionally completed by electrical engineers. Beneath the relationship between the Arduino and art lies an alliance of engineers, artists and designers. Many cross-disciplinary team efforts revolve around the Arduino within learning environments, work spaces and online. Often a team consisting of an engineer and an artist or designer will create works together, drawing on one another's strengths. The skill sets of the teams expand by collaborating with people of diverse backgrounds on the common platform which the Arduino microcontroller provides. The Arduino community threads together borrowed code, inspires new ideas, provides examples and starting points for non-technical users. The Arduino microcontroller proves to be instituted the way it was intended by its developers. It is an easy-to-use, adaptable, open source, and used in art and design. Reviews of earlier artist tools, roles within the Arduino community, and effects of an open source approach for designing the Arduino microcontroller are included in Section 4.1.

Second, art and design pieces have been a driving force to modifying the Arduino microcontroller. Several different versions of the board have been created for art and design purposes. The Arduino microcontroller is transformed through modifying designs

[4] Processing. http://processing.org/
[5] Wiring. http://wiring.org.co/
[6] An input/output (I/O) board refers to a microcontroller that inputs and outputs data through pins.

from the open schematics[7] available online, or the creation of shields.[8] Both the Arduino's physical shape, or footprint, and its operative abilities have been modified by artists and designers to best execute their work. In many situations studied, it was more important to keep the structure of the design or artwork intact, while the Arduino microcontroller was malleable in a number of ways. The Arduino does not always abide by 'form follows function', as authored by Louis Sullivan.[9] The functionality of the Arduino often followed the structure of the object embodying it. However, at times the function was independent of the form. Both form follows function and the inverse, function follows form, will be discussed in Section 4.2. The LilyPad Arduino, discussed in Section 2.2, is an example of a microcontroller that was modified both for its form and function.

Finally, a byproduct of the Arduino is its effects on creativity. The creative process contains the notions and lineages from which creative thoughts emerge. Thanks to the Arduino's usable design, users spend less time figuring out the inner workings and more time experimenting and discovering how it can be used in different environments or scenarios. The Arduino community also helps inspire other Arduino users. The creative process as it relates to the Arduino will be further discussed in Section 4.3 of this article.

An understanding of the open source initiative is integral for the research presented. The open source initiative is defined as

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[7] Board layout and board design refer to the printed circuit board (PCB) that the components sit on as a support. Schematics are the designs of a board which show the components and electrical traces revealing how the board works.
[8] Shields are custom extension boards.
[9] H.H. Arnason, *History of Modern Art*, 5th ed (Upper Saddle River, NJ: Prentice Hall, 2004), 79.

> "a development method for software that harnesses the power of distributed peer review and transparency of process. The promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in."[10]

Open source licenses include the creative commons license discussed in Section 2.1.3. The above definition specifically describes the application to software, but many things apply, including hardware and the Arduino microcontroller.

The terms new media art and interactive art encompass the artworks of the interviewees best. However, neither new media art nor interactive art is well defined in the field of art history. *Oxford Art Online*[11] represents the most authoritative source for art and art historical definitions, but did not contain a definition for new media art or interactive art. In *Art of the Digital Age*[12], Bruce Wands includes Interactivity as "A dialogue between the viewer and the art". Gerfried Stocker in *Code*[13] speaks of digital media art as "a dynamic system as engendered by an interactive process [that] reacts autonomously to the participants and their environments..." Stocker later poses questions as other ways to define digital media art, exemplifying the ambiguity in identifying the field. Mark Tribe and Reena Jana in *New Media Art*[14] state, "New Media art and older categorical names like "Digital art," "Computer art," "Multimedia art," and "Interactive art" are often used interchangeably". Tribe describes the discretion of the terminology

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[10] "Open Source Initiative", http://www.opensource.org/ (accessed December 9, 2009).
[11] Grove Art Online, s.vv. 'Interactive Art," "New Media Art" http://www. oxfordartonline.com (accessed September 27, 2009).
[12] Bruce Wands. *Art of the Digital Age* (New York: Thames & Hudson, 2006), 11.
[13] Ars Electronica. *Code*. Stocker, Edited by Gerfried and Romana Staufer. (Austria: Hatje Cantz, 2003), 11.
[14] Mark Tribe and Reena Jana. *New Media Art.*(Köln: Taschen, 2006), 6.

points to time sensitive tags for the same type of art in different decades.[15] The artwork and designs at hand can typically be described as new media art, interactive art or interactive design.

2. Arduino influences Art

2.1 History of the Arduino

The Arduino microcontroller is a principle representative of the microcontrollers commonly used in art and design. Others in the field include Wiring,[16] Making Things,[17] PIC,[18] and the Basic Stamp.[19] The Arduino microcontroller was originally created as an educational platform for a class project at the Interaction Design Institute Ivrea[20] in 2005.[21] It grew from the previous work of the Wiring microcontroller designed by Hernando Barragán[22] in 2004.[23] From its inception, the Arduino was developed to engage artistic and design-oriented minds.

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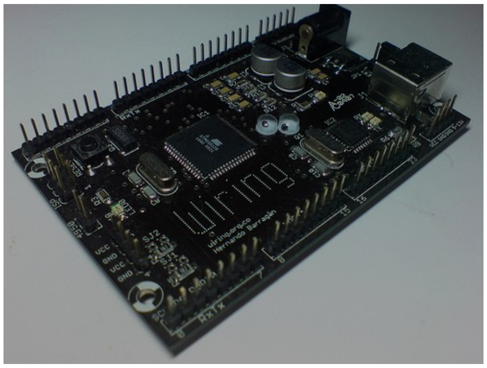
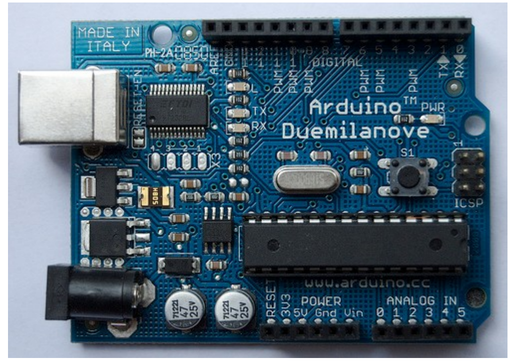
[15] Ibid.
[16] Wiring, http://wiring.org.co/ (accessed December 3, 2009).
[17] Making Things, http://www.makingthings.com/ (accessed October 6, 2009).
[18] Microchip Technologies, PIC, http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=2551 (accessed October 14, 2009).
[19] Parallax. http://www.parallax.com/ (accessed April 18, 2008).
[20] Interaction Design Institute Ivrea http://interactionivrea.org/en/index.asp. (accessed November 19, 2009). In 2005,the school merged with Domus Academy.
[21] ToDo, *The Interaction Ivrea Prototyping Toolbox.* (http://www.todo.to.it/#projects/idii, n.d.)
[22] Hernando Barragán (Creator of the Wiring microcontroller), in discussion with the author, September 2009.
[23] Hernando Barragán, "Wiring: Prototyping Physical Interaction Design" (master's thesis, Interaction Design Institute Ivrea, 2004).



2 *Wiring microcontroller,*2004, 3.6 in. x 2.4 in.
(Photograph provided by Marlon J. Manrique & Lezioni di Stile)



3 *Arduino microcontroller*, 2008, 2.7 in. x 2.1 in.
(Photograph provided Nicholas Zambetti)

Barragán, an artist and designer, created the Wiring microcontroller, Fig 2, to be used as a tool for a parsing data to electronics. He intended it to be used by a "non-technical" audience: "artists, designers, and architects," in short, not requiring prior electrical engineering or computer science knowledge. He emphasized the Wiring board as a prototyping tool. Wiring fulfilled Barragán's need for a designer-friendly tool (in this case a microcontroller) that was easy to use without a great deal of engineering or programming experience. Barragán's advisors for his thesis on Wiring were Casey Reas and Massimo Banzi. Reas created the visual programming language Processing[24] with Ben Fry. Reas studied interaction in art as an undergrad,[25] continued with John Maeda while at MIT, and developed Processing for a language accessible to artists and designers. Banzi, on the other hand was more interested in further developing the microcontroller as an art and design tool. The Arduino, Fig 3, was originally developed for an interaction design class taught by Banzi. The creators of the Arduino are Massimo

[24] Processing. http://processing.org/
[25] Casey Reas, "Behavioral Kinetic Sculpture" (bachelor thesis, University of Cincinnati, 1996).

Banzi, David Cuartielles, Dave Mellis,[26] Gianluca Martino with Nicholas Zambetti.[27] The Arduino team[28] currently consists of Banzi, Cuartielles, Martino, Mellis and Tom Igoe.[29]

The Arduino team wanted to further simplify the Wiring platform and thus the Arduino microcontroller was developed. The Arduino team made the Arduino microcontroller more usable by focusing on simplicity, a goal in pursuit of designing for a non-technical audience. Four cohesive reasons are echoed by Banzi when defining the Arduino's success.[30] These reasons also denote Arduino's differences from other similarly intended microcontrollers for artists and designers:[31]

1. It is inexpensive.
2. It is packaged with the Integrated Development Environment (IDE).
3. It is programmable via USB.
4. It is supported by a community.

The above points were deliberate decisions when the Arduino platform was being conceptualized and designed. The usability of the Arduino platform is significant being that every person interviewed spoke directly of the usability of the Arduino. Three people interviewed currently work at IDEO, and are experts in the field of usability. Participants were asked how they would describe the level of entry to the Arduino versus other microcontrollers. The answer was unanimous that the Arduino was easier to use. From having a simplified platform with a chip on board to a user-friendly Integrated Development Environment (IDE), made a difference to new users and people who

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[26] David Mellis (Co-creator of the Arduino microcontroller), in discussion with the author, November 2009.
[27] Nicholas Zambetti (Co-creator of the Arduino microcontroller), in discussion with the author, June 2009.
[28] Arduino, "Credits," http://arduino.cc/en/Main/Credits (accessed March 11, 2008).
[29] Tom Igoe (Member of the core Arduino team), in discussion with the author, August 2009.
[30] Massimo Banzi, *Getting Started with Arduino* (Sebastopol, CA: O'Reilly, 2009).
[31] Ibid.

appreciate visual aesthetics. Mellis comments that their goal was to make it less expensive and smaller than the Wiring board, “A lot of things people tend to build initially tend to be simple, they don’t need a powerful microcontroller”. Ninety-Four percent of interviewees felt the four points outlined by Banzi; cost, an integrated IDE, programmable over USB, and supported by a community, were useful in their work and made the Arduino a successful platform.

2.1.1 Cost

Fifteen people voluntarily commented on the cost of the Arduino relating to the importance of DIY without being prompted by a question about cost. The Arduino microcontroller costs about $35 USD[32], while Arduino’s precursor Wiring is $85 USD[33]. The inexpensive option available for the Arduino microcontroller is influential for two reasons given in the interviews conducted. First, when a replacement is financially within reach, the fear of destroying the original diminishes and drives up experimentation and creativity. Destroying something that is cheap is much more forgiving on your pocketbook and your mindset when learning something new. Second, the Arduino is affordable, allowing it to be embedded into projects permanently. David Zicarelli[34] observed:

> “I was really struck by the idea of what a radically inexpensive computer could mean to people making art -- a design goal of the Arduino project was that you

[32] Arduino, “Buy,” http://arduino.cc/en/Main/Buy (accessed May 28, 2009).
[33] Wiring, “Wiring hardware. Overview.,”://wiring.org.co/hardware/index.html (accessed April 5, 2009).
[34] David Zicarelli (Creator of programming language MAX), in discussion with the author, June 2009.

> could make installations and not have to tear them apart when you were done because you needed your laptop to read your e-mail."

Artist Rebecca Stern[35] uses the Arduino because they are inexpensive enough for her to leave in her artwork. Stern used a different microcontroller, the PIC in graduate school, previous to working with the Arduino microcontroller. PIC chips themselves are cheap, but the closed-source programmer costs $70-90 USD[36]. She asserts that the proprietary and expensive nature of the PIC would prevent her from leaving it in projects, "The PIC was only accessible to me when I worked in the computer lab at school and the propriety [PIC] programmer was paid for by the lab."

Other microcontrollers available on the market are the Basic Stamp, priced around $80 USD[37], and the Making Things microcontroller for $85 USD[38]. There are also cheaper Arduino boards made available from within the Arduino community. An example is the Freeduino priced at $26 USD[39], Fig 4. The Freeduino is designed from the same schematics as the Arduino, but not supported or branded by the Arduino company. The open source initiative allows cost to be driven down to the lowest price.

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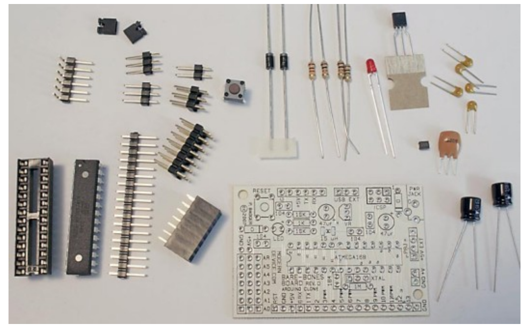
35 Rebecca Stern, (Artist and journalist for Craft and Make), in discussion with the author, September 2009.
36 MicroEngineering Labs, Inc, http://microengineeringlabs.com/ (accessed May 28, 2009).
37 Parrallax, http://www.parallax.com/ (accessed May 27, 2009).
38 Making Things, "Arduino Comparison," http://www.makingthings.com/arduino-comparison (accessed May 28, 2009).
39 Freeduino, "Buy," http://www.freeduino.org/buy.html (accessed May 30, 2009).

4 The Freeduino, 2.7 in. x 2.1 *in.* (Photograph provided by solarbotics.com)



5 *The Bare Bones Board,* 2.7 in. x 2.1 *in.*, (Photograph provided by moderndevice.com)

Another example is the Barebones kit, as seen in Fig 5, is sold as loose components to be soldered to the board, thereby removing the manufacturing cost of boards. The Barebones kit costs $20 USD,[40] and the blank PCBs[41] and individual components are also available for purchase. The BoArduino is another option available for $17 USD.[42] Although Arduino does not officially support these boards, they all function on its open source software. The significant implication of an inexpensive microcontroller is that it drives up the total number of artworks designed with the Arduino microcontroller.

2.1.2 Accessing the Arduino

Microcontrollers need to be programmed with software. Programs are written in the free, downloadable Integrated Development Environment (IDE) designed for the Arduino. The IDE includes three sections integrated together: the programmatic text editor, the compiler, and the debugger. The text editor is where code is written or pasted.

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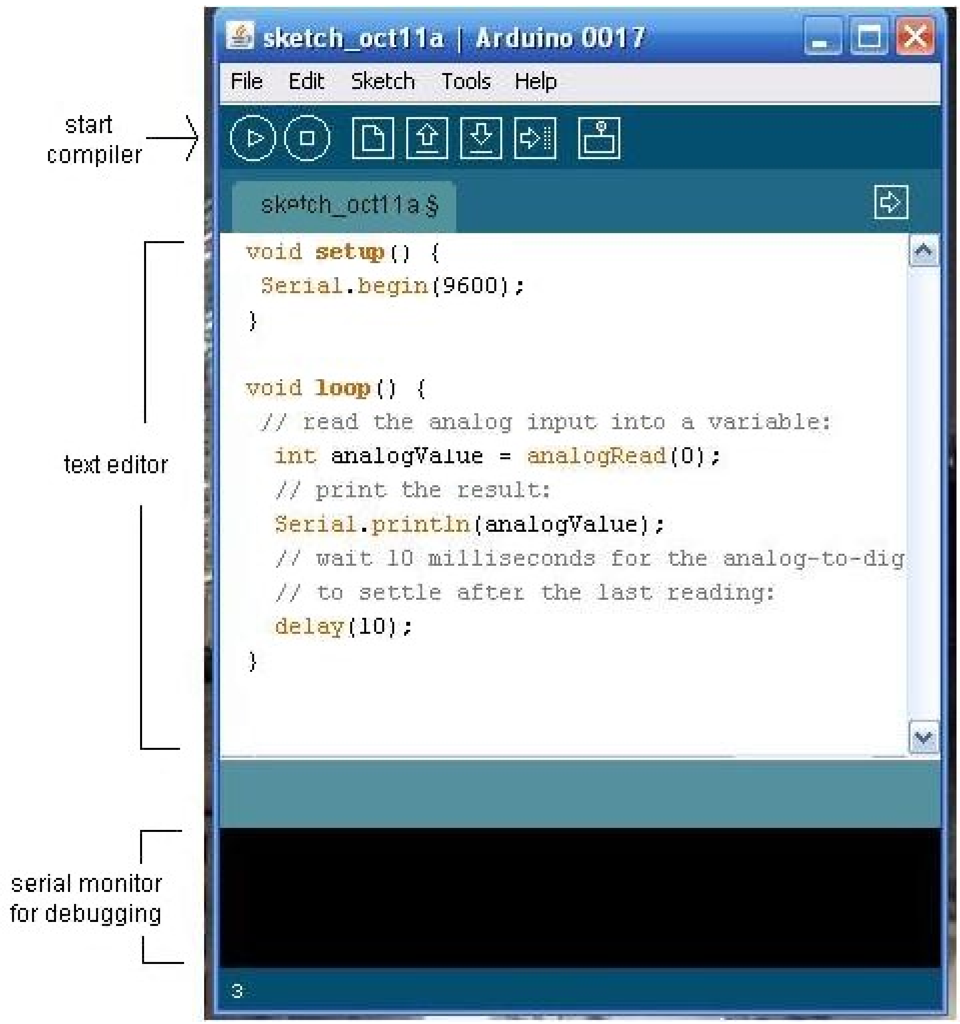
[40] Modern Device, "Bare Bones Board," http://moderndevice.com/ (accessed May 27, 2009).
[41] Printed Circuit Boards
[42] Adafruit Industries, "BoArduino," http://www.adafruit.com/index.php?main_page=index&cPath=19 (accessed May 30, 2009).

The complier compiles code when the ‘Upload to I/O Board’ button is pressed. A single button to compile code is a unique instance. The serial monitor can be used for debugging and monitoring data from your program. The debugger provides feedback, fostering confidence to move forward at a rapid pace. The IDE displays the interface for these three sections, as displayed in Fig 6.



6 *A screenshot of the Arduino IDE*

The IDE can be downloaded on many platforms which helps the Arduino grow at its current rate. It is compatible with the major computing platforms: Linux, Windows and Mac.

Arduino draws off both the Wiring and Processing code and software libraries in the IDE. The Wiring microcontroller is designed with the intention "to make comprehensible and useful things out of the things that looked cryptic…" according to Barragán. Barragán wrapped technical code into software libraries,[43] which made it easier for artists and designers to prototype their ideas. Igoe explains how the Arduino has attempted this: "Arduino embodies what I call glass box encapsulation. That means that you don't have to look at the lower level code that comprises the libraries if you don't want to, but you can if you choose."[44] In other words, the glass box encapsulation helps beginners by automating some code through software libraries. Experienced users may need to access and alter specific aspects of the Arduino code, such as libraries and this option is available to them. Mark Gross[45] delineates the accessibility of the Arduino microcontroller similarly to Igoe: "… to use Seymour Papert's slogan, 'low threshold, no ceiling'. Seymour's insight was to provide people with a very powerful (but simple) environment that allowed them to access the core ideas of computing, and to harness those ideas for their own multifarious purposes." For example, it is not readily apparent to most non-technical users that the programming language is derived from C/C++. Zambetti recollected this was a conscious decision as C/C++ is often seen as an intimidating barrier. Twelve interviewees agreed that if people knew they were using C/C++ with Arduino, the task would have appeared more daunting and turned off beginners, themselves included.

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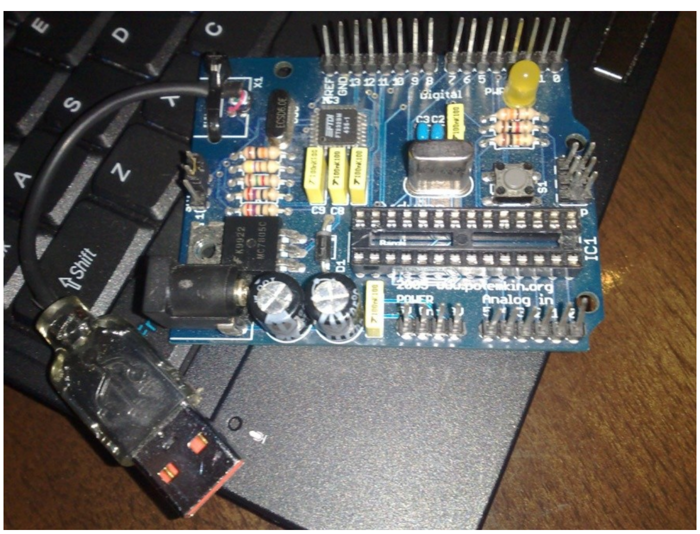
[43] Software libraries are written as a layer of abstraction between low level and high level programming.
[44] Trevor Clarke, "The A-Z of Programming Languages: Arduino's Tom Igoe," interview with Tom Igoe, *ComputerWorld,* October 12, 2009, http://www.computerworld.com.au/article/321749/-z_programming_languages_arduino_tom_igoe?. (accessed October 14, 2009).
[45] Mark Gross (professor of architecture at Carnegie Mellon University) in discussion with the author, September 2009.

Attaching the Arduino microcontroller to a computer via USB is another way the Arduino assists non-technical users. Serial ports are more difficult to come by on modern computers, whereas the USB port is currently available on most. On the Arduino, the serial interface is bussed through USB, replacing a serial connector with a USB connector. The first Arduino boards had the USB cable attached; an example is pictured in Fig 7. Currently the Arduino uses a separate USB, which Dave Vondle[46] finds useful for rapid prototyping on the go:

> "Arduino is more portable than any other electronic prototyping platform for design. A user does not need to use it in the confines of a lab where special computers or other components are needed. The Arduino is a singular unit and connects with USB, the most common standard for connecting devices which makes it accessible outside a lab environment".



7 *Arduino microcontroller,* 2005 (Photograph provided by Alicia Gibb)
Provenance: Nicholas Zambetti

[46] Dave Vondle (Creator of the Arduino mini shield) in discussion with the author, September 2009.

The Arduino in Fig 7 has male headers rather than female headers as pins. Compare the male headers to the female headers, pictured in Fig 3. Female headers are an intuitive benefit to the Arduino according to engineer Tod Kurt:[47] "the standard Arduino board is ready-to-use out of the box and has sockets [female headers] instead of pins [male headers], people know how to stick stuff into sockets." Zambetti expressed that female headers versus male headers were a discussion topic when making revisions to the Arduino board. The headers were changed to female for the same statement echoed by Kurt. People are familiar with plugging things in, which makes this action intuitive rather than challenging. The Arduino's plug and play nature makes it easy to understand and easy to manipulate the interaction of a project. Another aspect that makes the Arduino microcontroller easy to understand is its community.

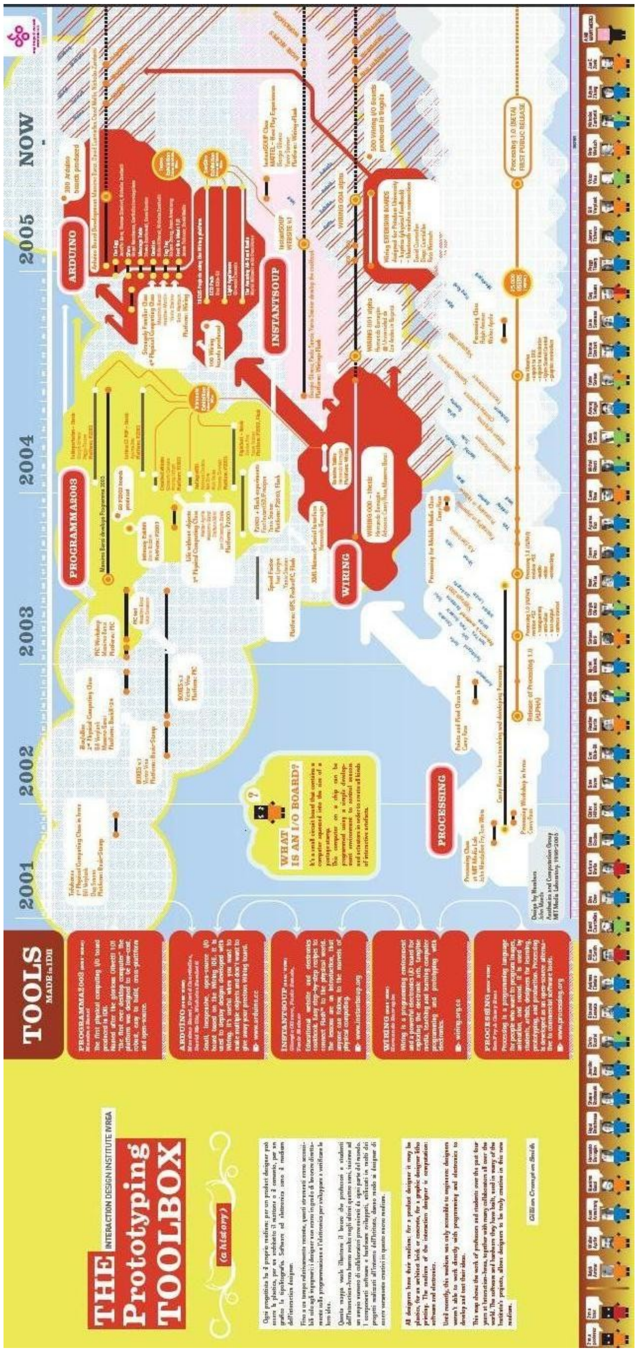
2.1.3 Supportive Community

The Arduino's board design evolves because of an active community of users who support both the history and future of the product. The Arduino microcontroller advances in its hardware design, software examples and popularity because users document and share code and designs. Open source platforms such as the Arduino microcontroller builds upon the creativity of an entire group of people rather than the small team from which it originated.[48] Arduino is licensed with a share-alike creative commons license. With this license, users of the Arduino are able and encouraged to share designs, reuse, and remix these designs to adapt the Arduino for their work.[49] Several community

[47] Tod Kurt (Co-creator of BlinkM's and many influential Arduino hacks), in discussion with the author, September 2009.
[48] Eric Von Hippel, *Democratizing Innovation* (Cambridge, MA: MIT Press, 2005).
[49] Arduino, http://arduino.cc/en/Main/Policy (accessed December 3, 2009).

members responsible for the Arduino's evolution are the artists and designers highlighted in this thesis. However, artists and designers are not working in a vacuum to evolve the Arduino microcontroller. The Arduino microcontroller has rapidly infiltrated different user groups simultaneously so that many areas of study are overlapping. These groups that have had an impact on the Arduino include but are not limited to engineers, hardware hackers, interaction designers, artists, educators, and robotics enthusiasts, exemplified in Section 3.2. Microcontrollers, traditionally used by engineers, are now in the hands of artists and designers working with the Arduino, and vice versa. Engineers are also creating artwork and design pieces. The various groups are blending and using each other's code, materials, and techniques. The lineage behind the Arduino is shown in Fig 8. The timeline in Fig 8 touches upon influential people behind the designs that guided the Arduino development: Programma[50], Wiring[51], Processing[52] and InstantSOUP.[53]

[50] ToDo, TheInteraction Ivrea Prototypers Toolbox, todo.to.it/#projects/idii
[51] Wiring, http://wiring.org.co/ (accessed December 3, 2009).
[52] Processing. http://processing.org/ (accessed December 3, 2009).
[53] Nastypixel, InstantSOUP, http://www.nastypixel.com/prototype/project/instantsoup (accessed December 3, 2009).

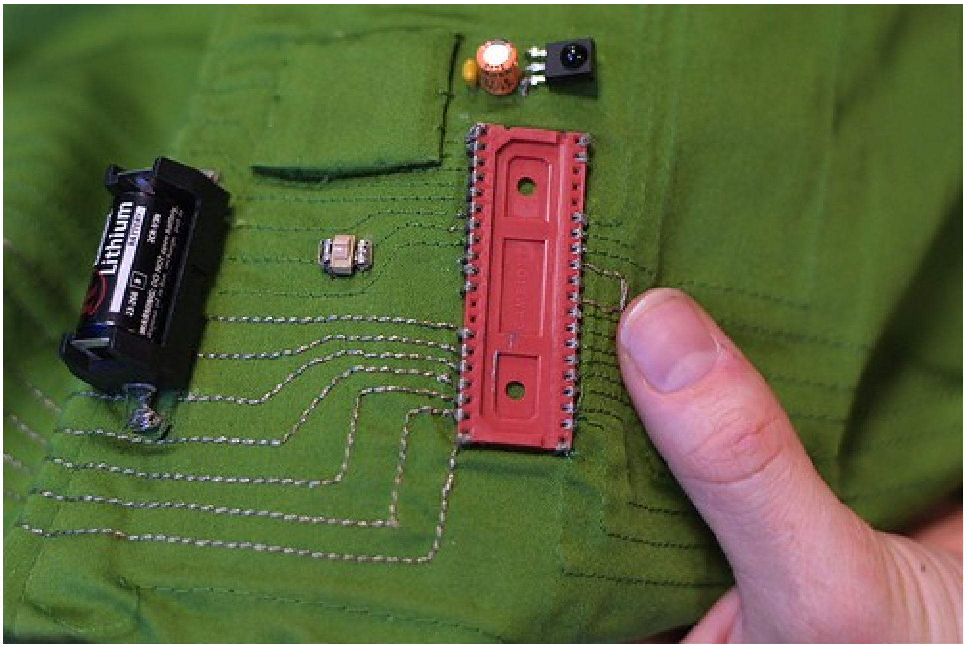


8 ToDo, *TheInteraction Ivrea Prototypers Toolbox* (file provided by todo.to.it/#projects/idii)
Patronage: IDII

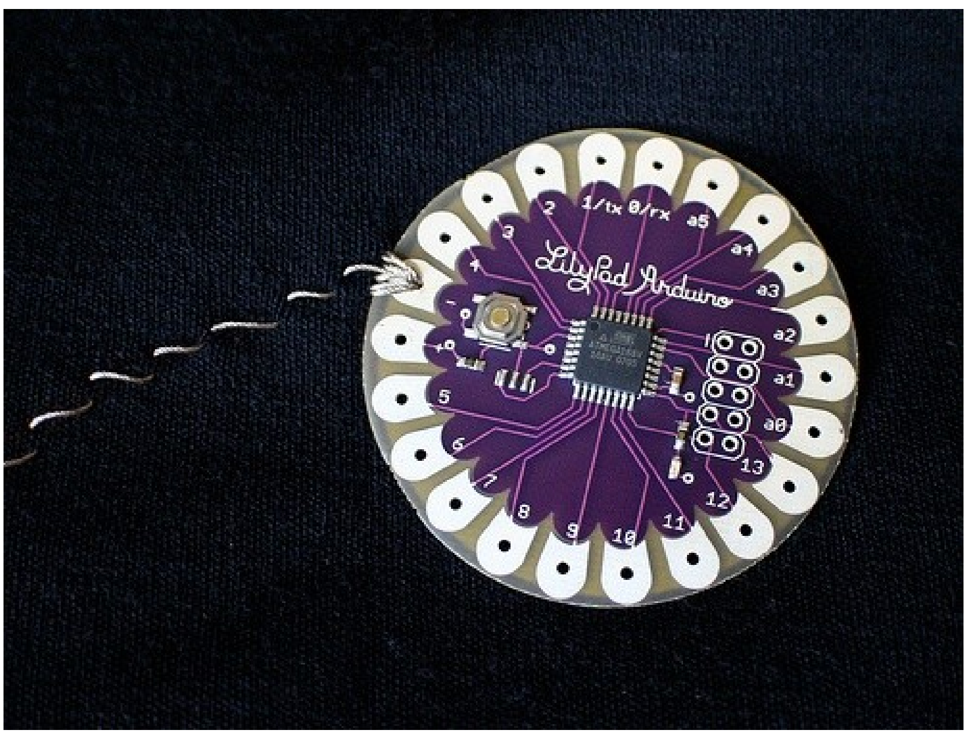
2.2 Benefits of the Arduino in artistic process

An example of a community-driven design is the LilyPad Arduino.[54] The LilyPad Arduino is a wearable version of the Arduino designed to be sewn into fabric with conductive thread. The LilyPad was derived from the Arduino by Leah Buechley[55] to be a fully integrated soft circuit microcontroller that was visually appealing. Buechley originally designed the LilyPad Arduino for a children's soft circuit class, but it was immediately embraced by artists. Previously, Buechley used AVR microcontrollers to teach classes to design electronic textile. Programming a soft circuit meant removing the chip from the circuit design, placing it in the programmer, coding with various AVR software, and finally place it back in the circuit. Physically taking the chip out to program added a layer of complexity that was a tough hurdle for novices. Shown in Fig 9, Buechley described the shape of the AVR boards as being lumpy and awkward for sewing, with oversized components. For the design of the LilyPad Arduino, Fig 10, Buechley chose a surface mount chip which was smaller and lighter.

[54] Arduino, "LilyPad Arduino," http://www.arduino.cc/en/Main/ArduinoBoardLilyPad (accessed May 15, 2009).
[55] Leah Buechley (Creator of the LilyPad Arduino) in discussion with the author, June 2009.



9 Leah Buechley, a soft circuit sans chip previous to the Arduino LilyPad (Photograph provided by Jean-Baptiste Labrune)



10 Leah Buechley, *The LilyPad Arduino,* 2” in diameter, (Photograph provided by Leah Buechley)

Designing the LilyPad, based on the Arduino's open source schematics allowed for a microcontroller that was all one piece, and could glean support from the existing Arduino community. With the help of Jean-Baptiste Labrune[56], another Arduino community member, they realized a circular shape would enhance the functionality, providing more pads around the perimeter of the board. The copper pads are also widened around the circumference for secure sewing. These pads were formed due to the circular design of the LilyPad and created a radiating area which provides the function of being able to get a strong contact between the thread and the surface area of the copper pad. The thread in Fig 10 is conductive thread made with metal filament and illustrates that the LilyPad can be sewn to fabric through its conductive pads which act as pin outs. This is an example of modifications benefiting from both form and function.

The LilyPad Arduino, which is purple with decorative cursive text, was designed to be aesthetically pleasing. It is circular in shape, resembling a flower, with radiating petals as the I/O pins. The LilyPad has a low profile form making it flush with fabric. Artist, Stern considers the LilyPad the most aesthetic board and she feels "it helps artists to be less intimidated by microcontrollers because it looks different than other electronics".

Contrast Buechley's experience making her own microcontroller to James Seawright's[57] experience using antecedent microcontrollers. Seawright has been creating interactive art since the 1960's, previous to the advent of the Arduino. Seawright is a pioneer in the field of microcontroller-based art. Seawright had fewer choices when

[56]Jean-Baptiste Labrune (Early adapter of the Arduino microcontroller) in discussion with the author, August 2009.

[57] James Seawright (Artist creating interactive artwork since 1960) in discussion with the author, March 2009.

choosing microcontrollers or computers, none of which were designed for artists or designers. In 1971[58] he created *Network IV* which was installed at the Seattle Airport, SeaTac.[59] He described the computer as awkward and enormous. The program took Seawright 30 minutes to run on punch tape through a Nova computer. Within two years, it was obsolete and the airport could not manage the upkeep costs. By 1987 he was working with the Motorola 68hc11[60] microprocessor which was about the size of a paperback book. He would spend entire days revising one piece of the program because single line revisions were not permitted on the chip, thereby requiring him to rewrite the entire program. Before the PIC, with which he could edit single instances of code, programming would take months because there was no way to speed up the computational process. With the PIC, programming was completed faster than the creation of the physical piece. The microcontrollers used were not flexible and Seawright did not attempt modifying their complexity. None of the microcontrollers that Seawright used were designed for artists. Seawright also discussed the topic of preservation with his art. All of his artwork was intended to be interactive, but in museum settings today his pieces are either not in interactive settings or no longer function. The meaning behind his art is the social patterns created from interaction and is, ironically, lost to history. Seawright's experience lets us glimpse into the past to see how far we have come. Especially in making microcontrollers accessible and useable, as demonstrated by Buechley who created her own.

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[58]The piece was in operation since the end of August 1973. This slightly predates Pong, and therefore has a claim to being the first ever computer game. The installation was not preserved, all that remains is a description of pressure sensor buttons that would deploy NE-40 lamps and sounds.

[59] Toby Paddock, e-mail to Dorkbot mailing list, July 21, 2005, http://www.music.columbia.edu/pipermail/dorkbotsea-blabber/2005-July/001334.html

[60] Daniël v/d End, "Motorolla 68HC11 Microcontroller," Rijswijk Institute of Technology, n.d., http://www.xs4all.nl/~hc11/thrsim11/68hc11/index.htm (accessed August 19, 2009).

2.3 Arduino in the Mainstream

The Arduino is off to a relatively strong start.[61] In its first two years Arduino sold 50,000 boards, according to the article featuring the Arduino team in *Wired Magazine*.[62] As of August 2009 the official number sold was 100,000 according to Alexandra Deschamps-Sonsino[63], CEO of Tinker.it. Tinker.it is a company which partners with the Arduino microcontroller and has Banzi on staff as CTO. The research at hand shows that Arduino is growing in notoriety within art and design. Since 2005, the variety of Arduino microcontrollers has grown substantially. As of 2009 the Arduino hardware index[64] displayed thirteen different boards, several having multiple versions. That number does not include the uncountable derivatives produced by the Arduino community under the creative commons license.[65] The most recent version of the Arduino is the Duemilanove released in October of 2008.[66]

Searching beyond the scope of Arduino's figures, Google[67] was consulted to reveal search results. In 2009, the term Arduino is found in 1.9 million websites. The boolean operation 'Arduino and Design' pulled up 613,000 sites, and 'Arduino and Art' had 603,000. Google Trends[68] is a service provided by Google with algorithms that show trends and correlation based on search terms from 2004 to the present. The graph in Fig 11 shows 'Arduino' as a singular search term. There is a jump in 2005 when the Arduino

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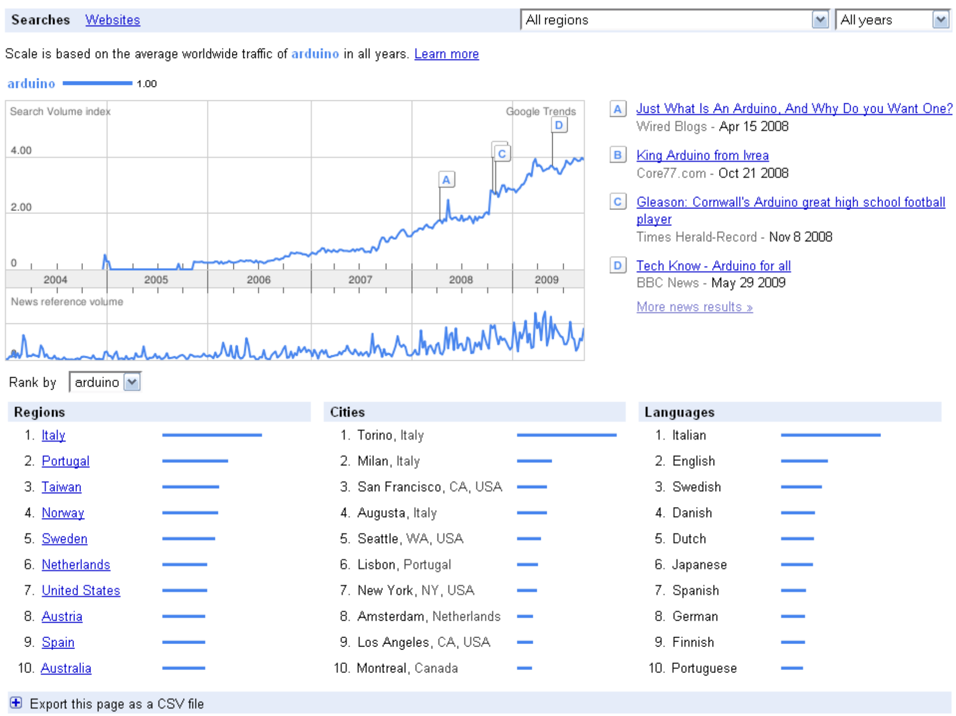
[61] Justin Lahart, "Taking an Open-Source Approach to Hardware," *Wall Street Journal*, November 27, 2009, http://online.wsj.com/article/SB10001424052748703499404574559960271468066.html
[62] Clive Thompson, "Build It. Share It. Profit.," *Wired*. (November 2008): 166-176.
[63] Alexandra Deschamps-Sonsino (CEO of Tinker.it) in discussion with the author, November 2009.
[64] Arduino, "Hardware," arduino.cc/en/Main/Hardware (accessed November 4, 2009).
[65] Creative Commons, http://creativecommons.org/ (accessed June 13, 2009).
[66] Arduino, "Hardware," arduino.cc/en/Main/Hardware (accessed November 4, 2009).
[67] Google, http://google.com, (accessed October 23, 2009).
[68] A beta project from Google Labs.

project was released. From 2005-2009 there is continuous growth of the term 'Arduino' used in websites according to Google Trends. The X axis of the graph shows a timeline from 2004-2009. The Y axis shows the average search traffic for the term 'Arduino'. The data is scaled on the relative average search traffic.[69]



11 *Google Trends graphs of the term Arduino*

The following phrases were googled: 'Arduino and Art' and 'Arduino and Design' in 2008 and 2007[70] using Google Trends.[71] Google Trends retrieves data based on searches containing both terms on a webpage. In 2009, the terms 'Arduino' and 'Design' have more trends found together than 'Arduino' and 'Art' do. The trends for each do not yet show strong correlations, but show growth in popularity with the Arduino in art and design terminology since 2005. The significance of finding data in Google Trends shows

[69] Google Trends, http://www.google.com/intl/en/trends/about.html#7 (accessed October 23, 2009).
[70] The 2009 data is not yet complete.
[71] The numbers are generalized numbers over a period of time from Google's search data. Google Trends works by analyzing algorithms based on search data: http://www.google.com/intl/en/trends/about.html#7

a cultural expectation for a relationship between art or design and the Arduino microcontroller, concluded by the frequency of search traffic for those terms.

2.4 Arduino in Museums

The Arduino as a tool for artists and designers is being introduced in art museums and galleries. The growing popularity both in the mainstream and museums reveals that artists and designers are embracing this as a tool for their medium, as the tool was intended. Edward Shanken reports that "… throughout history, artists have created and utilized technology to envision the future, not just of art, but of culture and society in general."[72] The Arduino's path into museums closely resembles the route of photography into art museums by way of science museums in the 1800s. At first, photographs were seen as a new technology belonging to science rather than an art.[73] Science museums, conferences, and galleries tend to lead the exhibition of artwork involving technology.[74] Arduino artwork can be found in several science museums, on Arduino's Exhibition[75] webpage, and a handful of art museums.

The Arduino's Exhibition page functions as a virtual art gallery for Arduino.[76] For several artists using the Arduino microcontroller, online exhibits are the first place their pieces are shown. Arduino's forums, blog and website each designate an entire subject thread, category, and page (respectively) to exhibition, which is an area to talk about

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[72] Edward A. Shanken, "Concluding Reflections: Art History, Interdisciplinary Collaboration, and the Interpretation of Hybrid Forms," In *Media Art Histories* (Cambridge, MA: The MIT Press, 2007), 65.

[73] Karen A. Verschooren, ".art: Situating Internet Art in the Traditional Institution for Contemporary Art" (master's thesis, Massachusetts Institute of Technology, 2007), 97.

[74] Frank Popper, *From Technologies to Virtual Art* (Cambridge: MIT Press, 2007).

[75] Arduino, "Arduino: Playground," http://www.arduino.cc/playground/Projects/ArduinoUsers (accessed May 19, 2009).

[76] On Arduino's website, engineers, artists and designers are all celebrated as makers who contribute to the project.

what Arduino users have created.[77] The Ar(t)duino section of the Arduino blog is most likely the first exhibit of the Arduino in art, albeit virtual. Science museums that have hosted Arduino include the Museum of Science and Industry[78], Ars Electronica[79], the Exploratorium[80] and the Science Museum of Minnesota.[81] Conferences such as ACM's SIGGRAPH[82] are also a welcoming place for computer driven art featuring new technologies.

The examples that follow were chosen among the only instances of the Arduino in art museums which include modified Arduino designs for the sake of art and design. Three of the four artists exemplified have modified the Arduino board for various projects: Usman Haque[83], Bjöern Hartmann[84], and HC Gilje[85]. Rebecca Stern is an artist that uses the LilyPad which was modified from the Arduino by Buechley. Stern created an art piece entitled *LilyPad Embroidery: A Tribute to Leah Buechley*, Fig 12, which exposes the LilyPad as her tool.

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[77] Arduino Forums, http://www.arduino.cc/cgi-bin/yabb2/YaBB.pl (accessed September 26, 2009).

[78] Museum of Science and Industry, "Smart Home: Green + Wired," http://www.msichicago.org/whats-here/exhibits/smart-home/ (accessed October 18, 2009).

[79] Ars Electronica Archive, "Digital Communities," http://90.146.8.18/en/archives/prix_archive /prix_projekt.asp?iProjectID=13789 (accessed October 18, 2009). Ars Electronica was originally constructed to be a museum of the future.

[80] Exploratorium, "Learning Studio," http://www.exploratorium.edu/ls/collaborators.html (accessed October 18, 2009).

[81] Science Museum of Minnesota, http://www.smm.org/adultprograms/catalog/ (accessed October 18, 2009).

[82] ACMSIGGRAPH, http://www.siggraph.org/ (accessed October 18, 2009).

[83] Usman Haque (Founder of Haque Design + Research) in discussion with the author, September 2009.

[84] Bjöern Hartmann (Creator of Phidgets shield for the Arduino microcontroller) in discussion with the author, September 2009.

[85] Hc Gilje (Creator of the Arduino-Standalone) in discussion with the author, October 2009.

12 Rebecca Stern *LilyPad Embroidery: A Tribute to Leah Buechley*, 2008, LilyPad, sensors, embroidery, (photograph provided by Rebecca Stern) Provenance: BildMuseet, Museum of Craft and Folk

Stern's piece was originally shown in the Open Source Embroidery exhibit at BildMuseet in Umeå, Sweden. The Museum of Craft and Folk Art of San Francisco also exhibited Stern's *LilyPad Embroidery: A Tribute to Leah Buechley*. *LilyPad Embroidery: A Tribute to Leah Buechley* is an embroidered design around the LilyPad Arduino. It uses a light sensor (a photocell) to increase or decrease the rate at which the LEDs blink and the speaker beeps. [86] Below two people are interacting with the embroidered piece by covering the light sensor which rapidly blinks the LED and increases the metronome coming from the speaker.

[86] Sternlab, "LilyPad Embroidery," http://sternlab.org/2008/04/lilypad-embroidery/ (accessed October 5, 2009).

13 Interaction with Rebecca Stern's *LilyPad Embroidery: A Tribute to Leah Buechley*, 2008, (photograph provided by Rebecca Stern). Installed at the Cartel Coffee Lab.

In her piece, Stern asserts the beauty of the LilyPad as her artist's statement. Stern feels that artists can identify with the Arduino microcontroller because it catches the eye in its aesthetics, which was why she attributed her artwork to Buechley. What makes this piece unique is that the artists' tool has not previously been the centerpiece of an artwork. Paul asserts that "museums and galleries commonly have to build structures or walls to hide 'ugly' computers and need to assign staff to the ongoing maintenance of hardware". [87] In the instance of Stern's piece, the hardware is celebrated.

Another example is Haque's *Remote* created using an Arduino. *Remote* was a commission of the New Radio and Performing Arts, Inc. for the Mixed Realities

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[87] Christine Paul, "The Myth of Immateriality: Presenting and Preserving New Media," in *Media Art Histories* (Cambridge, MA: The MIT Press 2007), 252.

Exhibit.[88] In this exhibit, a chair was placed in a room at Emerson College in Boston (the first image in Fig 14) and another chair in the virtual space Second Life (the second image in Fig 14).[89] The virtual and real worlds trade humidity, temperature, light, speech, mist, wind, sound, and proximity data to effect one another's environments. If the chair in Boston is rocked from side to side in Boston, the cartoon chair in Second Life rocks from side to side. Avatars in Second Life can sit in the chair causing the mist machine to turn on in the room in Boston. Light sensors in Boston control the atmospheric light in Second Life. The wind in Second Life triggers fan speed in the room in Boston.

14 Usman Haque, *Remote*, 2008, Arduino, mixed media, Emerson College, Boston and Second Life.

Hartmann created the *Digital Dacha Murals: Affinity, Blueprint and Wishing Wall*[90] with Scott Doorley, Parul Vora, Kevin Collins, and Dan Maynes-Aminzade. The murals were displayed at the San Jose Museum of Art.[91] *Wishing Wall*, Fig 15, was a visual representation of the sounds of a person answering the question "What do you wish for?" into a telephone.[92] The *Wishing Wall* was built with one PC, an Arduino, two speakers, and a microphone, and the projection was running a Processing applet. The

[88] Turbulence, "Mixed Realities," http://turbulence.org/mixed_realities/ (accessed October 18, 2009).
[89] Haque Design + Research, "Remote," http://www.haque.co.uk/remote.php (accessed October 20, 2009).
[90] Bjorn.org, Digital Dacha Murals http://bjoern.org/projects/murals/ (accessed November 10, 2009).
[91] San Jose Museum of Art, http://www.sjmusart.org/ (accessed November 10, 2009).
[92] Dacha, http://digitaldacha.com/ (accessed November 10, 2009).

image below shows the telephone in use in the foreground and a visualization of the sound being projected in the background. It was displayed a second time at the ZeroOne Festival[93] which celebrates inspirations of art and technology.

15 Bjöern Hartmann with Scott Doorley, Parul Vora, Kevin Collins, Dan Maynes-Aminzade, *Wishing Wall,* 2008, PC, Arduino, two speakers, and a microphone*,* San Jose Museum of Art, California (photograph provided by bpunkt)

Wind-Up Birds, Fig 16, created by Gilje was installed outdoors as part of UT-21: Polish Norwegian Art Project. UT means 'out of the museum' or 'without title'.[94] Gilje's project introduced a new species of electronic bird to be accepted into the cultures of forest creatures. It took fifteen minutes for a woodpecker to perch on the same tree as one of the *Wind-Up Birds,* which were programmed to create woodpecker sounds, and it easily fooled human ears.[95] "This was the initial motivation for me, the movement of sound in a space, and the effort involved in trying to localize the source of the sounds

[93]Artsopolis, http://www.artsopolis.com/org/detail/502 (accessed November 10, 2009).
[94] HC Giljge's Blog, "Conversations with spaces," posted September 3, 2008, http://hcgilje.wordpress.com/2008/09/03/ut-21-polish-norwegian-art-project/ (accessed August 7, 2009).
[95] HC Giljge's Blog, "wind-up bird(s)," posted on September 4, 2008, http://hcgilje.wordpress.com/2008/09/04/wind-up-birds/ (accessed August 7, 2009).

which lead to a stimulation of our perceptive apparatus." Gilje used an Arduino StandAlone, an Xbee for wireless communication, and a solenoid for pecking. The pieces each had a roof to protect the electronics from the elements.

16 HC Gilje, *Wind-Up Birds*, 2007, Xbee, ATmega 168 microchip, solenoid with wooden box and metal roof, (photograph provided by: HC Gilje)

Furthering the growth of the Arduino microcontroller in art museums is Paola Antonelli,[96] a senior curator of Architecture and Design at MoMA in New York. The Arduino is something new in her field that she is currently learning about.[97] Antonelli sees an impact on art created from the Arduino just as Processing affected physical computing. The impact Antonelli articulates is that the Arduino microcontroller as a tool

[96] Paola Antonelli (Senior Curator of Design and Architecture at MoMA) in discussion with the author, October 2009.

[97] *Metropolis* "Paola Antonelli," *Metropolis*, April 2009, 108.

is more accessible to artists and designers, just as Processing debuted code that was centric to art and design. She states from her role as a curator, "If I know what it is about, then it must be a universal and accessible tool." Using herself as an example, she perceives that you don't need to know the low level bits to recognize the potential the Arduino microcontroller has. This statement mirrors the findings in Section 2.1. Antonelli states that "The basic bricks to design everything in the art world, such as the Arduino and the automation of objects, are becoming really open to the artists and designers themselves, and that's the big revolution of open source". Open source in the art world is interesting because it gives others the source code to recreate the same artwork. Antonelli requires the source code for both open and closed source artworks acquired by MoMA. Collecting code in this manner will make MoMA a library of all source code for their collected digital artworks. This would be equivalent to obtaining every paint recipe to accompany every painting in the collection.

The difference between the open source code is that the museum or the creator could publish this code for the public. The museum would not have those privileges with closed source code. Antonelli considers the code and the physical attributes as one; the piece would not exist without the source code or the hardware for both open source and closed source pieces. "Museums exist to preserve things," says Antonelli. However, preserving becomes complicated when collecting interfaces or websites, as the dimension of time erodes technology. It is difficult to acquire them in a static way when their living state was dynamic and interactive. Antonelli articulates,

> "What does it mean to acquire computational pieces, you have to acquire many different states; there are several ways. You can acquire the code, and the

> hardware that it originally ran on. But the original hardware may crash, and putting it on a new piece of hardware may appear phony, so you can record a video of it functioning and show it, or do a combination of those".

Open source projects as part of the art and design domain will be beneficial to the future preservation in art and design. Museum documentation for preservation of open source art works will be more accessible and easier to maintain than reverse engineering the technology to determine how it functions. However, there may be other preservation challenges that museums will need to explore. Several participants echoed maintenance and preservation concerns in their interviews. Some artists were concerned that their interactive piece would not be allowed to be touched and the entire point of their artwork would be overlooked. Nine artists were concerned that if their piece malfunctioned, the museums would not be properly staffed to fix it. From a curatorial perspective, museum staff modifying the code to fix artwork may alter the meaning or authority of the art. If the original software does not work, that also raises a question of which software version is appropriate to display, the original code or the code that functions. Versioning raises a question of what is the art; it could be considered the software, hardware, interaction or all of those. Some art may also need to have software updates to continue functioning. Participants who interact with the piece may change the physical positioning within the gallery so that other viewers have a different experience happening upon it. For future exhibits and documentation, the correct positioning could be argued in pieces that include interaction.

3. Method and Participants

3.1 Research Questions

A. What is the response to the Arduino microcontroller among artists and designers?

B. Why were modifications made to Arduino's hardware or software?

C. How is creativity affected with the Arduino microcontroller?

Given the highly qualitative nature of these questions, a case study was chosen to collect data. Data collection methods followed Yin's case study design.[98] Yin states case studies should be used when "why" and "how" questions are asked.[99] The case study method ensures that the topic is fully explored and multiple facets are revealed. The focus of the study answers why the Arduino is being used as an artist tool, why it is being modified, and how it influences the creative process. The contextual conditions of the semantics of the usage of the Arduino are relevant to the circumstance that art and design are the impetus of board modification.

3.2 Participants

Participants included artists, designers, curators, engineers, computer scientists, hardware hackers, or a combination of this list. Thirty-seven people were interviewed in total. Ten of the participants considered themselves to be more on the engineering side, eleven identified themselves as artists and eight people were designers. Five people felt they were equally on both sides of engineering and art or design. Three people were interviewed for a different purpose and the question did not apply. Ten were female and twenty-seven were male. The participants were chosen based on Igoe's advisement and

[98] Robert K. Yin, *Case study research: Design and methods,* 3rd ed., (Thousand Oaks, CA: Sage, 2003).
[99] Ibid.

the author's network of artists and Arduino enthusiasts. Two artists who work with different microcontrollers were interviewed for comparison. The array of people embodied in this section exemplifies the scope of the audience interviewed for this research.

Participant	**Mode**	**Current Location**	**Contribution**
Paola Antonelli*	Senior Curator of Design and Architecture	MoMA, New York	Influential supporter of Arduino in museums
Hernando Barragán*	Artist	Barraganstudio	Creator of the Wiring board
John Bennett	Artist	Skylab Gallery	Supporter of Arduino in galleries
Julian Bleeker	Designer	Near Future Labratory	Designer using and modifying Arduino
Jan Borchers	Head of the Media Computing Group	RWTH Aachen University	Creator of the LumiNet board
Jennifer Bove	Interaction Designer	Kicker Studio	Student from Ivrea
Leah Buechley	Engineering / Dance	MIT Media Lab	Creator of the LilyPad
Dario Buzzini	Interaction Designer	IDEO	Student from Ivrea
Alexandra Deschamps-Sonsino	CEO	Tinker.it	Tinker.it is the company behind Arduino
Rob Faludi	Artist	Interactive Telecommunications Program NYU, SVA	Co-creator of the LilyPad Xbee
Limor Fried	Founder & Engineer	Adafruit Industries	Influential hacker of Arduino
HC Gilje	Artist	Bergen National Academy of the Arts	Creator of the Arduino StandAlone
Dana Gordon	Designer	Design Consultant	Student from Ivrea
Mark Gross	Architect / Computer Scientist	Carnegie Mellon University	Studies tangible interaction toolkits and platforms
Usman Haque	Artist and designer	Haque Design + Research	Created shields and many pieces with the Arduino
Kate Hartman	Artist	University of Toronto	Co-creator of the LilyPad Xbee

Bjöern Hartmann	Designer / Computer Scientist	Berkeley Institute of Design at University of California Berkeley	Creator of Phidgets-Arduino shield
Jeff Hoefs	Artist	Smart Design	Hardware hacker with Arduino
Tom Igoe*	Designer and Author	Interactive Telecommunications Program at NYU	Arduino team member
Younghui Kim	Designer	Hongik University	Taught the class that produced DMDuino
Edith Kollath	Artist	NYC Resistor	New media artist using the Arduino
Josh Kopel	Artist	Kolaboration Studio	Artist using Arduino
Mike Kuniavsky	Designer	ThingM	Co-creator of BlinkM's
Tod Kurt	Engineer	ThingM and todbot.com	Co-creator of BlinkM's and a plethora Arduino hacks
Jean-Baptiste Labrune	Engineer / postdoctoral associate	Tangible Media Group, MIT Media Lab	Early adaptor and educator of Arduino workshops. Develops Creativity Research Tools for artists and scientists
David Mellis*	Interaction Designer	MIT Media Lab	Co-creator of the Arduino
Eric Pan	Engineer	Seeed Studio	Created Seeeduino and Rainbowduino among others
Douglas Repetto	Musician	Columbia University	Founder of dorkbot and artbot
James Seawright	Artist	Independent	Created interactive art before Arduino was released
Rebecca Stern	Artist / Journalist	Make / Craft magazines	Artist using Arduino and influential journalist
Peter Terezakis	Artist	Independent	Created art with different microcontrollers
Clive Thompson*	Journalist	Wired	Author of "Build It. Share It. Profit." article in *Wired* about the Arduino and open source
Phillip Torrone*	Design / Editor	Adafruit Industries / Make Magazine	Influential writer on Arduino
Dave Vondle	Engineer / Designer	IDEO	Creator of the Arduino mini shield
Fabian Winkler	Artist and Educator	Purdue University	Media artist using Arduino
Nicholas Zambetti	Computer Scientist / Designer	IDEO	Co-creator of the Arduino
David Zicarelli	Engineer	Cycling74	Creator of MAX

*People who were asked a different set of specific questions based on their role.

3.3 Questions & Format

The following questions were asked to first define how interviewees identify with the Arduino; second, to talk in depth about their Arduino projects; third, to define any modifications they made to the Arduino board; and finally to investigate their creative process with the Arduino in the ways it either achieved or limited their artwork. The format varied between in-person conversations, phone calls, Skype, instant messaging, and email. Nine participants were interviewed in person, three were interviewed over the phone, four were interviewed over Skype, two over instant message and nineteen were interviewed over email. All conversations were recorded with permission of the interviewee.

Background

1. What is your education/training in?
2. How did you get started with electronics?

Lineage with Arduino

3. When did you first hear about the Arduino?
4. When was your first project?
5. What was your first Arduino project?

Learning curve

6. Did you already know how to code?
7. What is your history with the Arduino?
8. How would you describe the learning curve to the Arduino vs. other microcontrollers you may have used?

About the Art

9. Have you created pieces that included modifications to the Arduino board?
10. What were the steps you took to create [title of piece]?
11. Was there something in your piece that you didn't get around to doing?
12. What motivates you to use Arduino in your artwork or designs?
13. Is there anything you attribute to the Arduino for enhancing your ingenuity or creative process?

Future of Art

14. What are you going to work on next?
15. What else do you wish the Arduino could do?

The results were aggregated into a spreadsheet based on the interview question or other common threads discussed in conversation, such as cost of microcontrollers, where artworks or designs were shown, and any further personal stories they had with the history of the usage of the Arduino. Because many interviews were conversational, the questions were not answered directly in every instance. Data was categorized according to the three research questions listed in section 4.1, and further analyzed to draw conclusions.

4. Results

4.1 What is the response to the Arduino microcontroller among artists and designers?

The Arduino microcontroller is an evolving tool for art and design. The Arduino can be thought of as the brain that runs the artwork or interactive design. It is the vehicle data runs through to convey art, similar to how a brush is a vehicle for paint. Four artists likened using the Arduino with electronics to using a paintbrush with paint. The Arduino differs as a tool from traditional artistic tools because it is embedded within the artwork. Prior to electronics, artists did not have to leave their tools in their works. Paintbrushes or chisels were not left in paintings or sculptures respectively. Leaving tools within the piece brings an additional cost to the artist or designer. Removing the Arduino from the piece altogether or writing over the chip changes the piece, and could destroy it. Christine

Paul comments that "…it would be highly problematic to ignore the art's material and components and the hardware that makes it accessible."[100] Ayah Bdeir wrote about electronics as material in her paper presented at Tangible and Embedded Interaction in 2009.[101] The Arduino and its components are materials for artwork, and as discussed in Section 2.4 have been shown in museum environments. The Arduino is used with multiple and diverse materials from traditional electronic components such as LEDs (Light Emitting Diodes), and sensors, to new found conductive materials, such as conductive thread and conductive paint. Another material is information. Raw data and code is a non-traditional material, increasingly prevalent with the turn of the century and the advent of the Information Age. Designer, Mike Kuniavsky[102] says "The Arduino is a tool that makes it easier to treat information processing as a material." Artists have always liked to make cultural commentary so it is only natural that in the Information Age, information and bits would become a material for art.

Arduino's open source initiative and the relationships developed within the Arduino community were two prominent topics interviewees discussed at length as to why the preferred the Arduino microcontroller. Other aspects discussed throughout were the usability of the Arduino microcontroller and the cost.

100 Christine Paul, "The Myth of Immateriality: Presenting and Preserving New Media," in *Media Art Histories* (Cambridge, MA: The MIT Press 2007), 252.

101 Ayah Bdeir, "Electronics as material: littleBits," (Invited paper, Tangible and Embedded Interaction conference, Cambridge, UK, Feb 16-18, 2009).

102 Mike Kuniavsky (Co-creator of BlinkM's and co-founder of ThingM) in discussion with the author, September 2009.

4.1.1 Open Source

The Arduino microcontroller is an open source project in its hardware and software which makes it a malleable tool. The open source nature of the Arduino microcontroller allows people to easily view and modify schematics, code, and examples. The boards have been copied to create different versions that have different functionality such as wireless functionality or motor control. Boards created by the Arduino community which have been influential in art and design according to the interviewees are: The LilyPad, LilyPad Xbee, the StandAlone Arduino, and the Book Radio microcontroller which influenced the Arduino Mini. Many more were created with the motivations of art and design such as the Rainbowdunio[103] from Seeed Studios with the slogan "Electronic can be art", LumiNet[104], created for an organic illumination network on clothing, or Sanguino[105], created for 3D printing. The open source movement is empowering for users to create their own versions of the Arduino microcontroller.

The benefit of open source is that many people are simultaneous developing the Arduino microcontroller independent of the company that makes it. The future of the Arduino will be full of shared knowledge. If the company that makes Arduino ceased to exist, the microcontroller itself would live on because the Arduino community could continue to build upon and benefit from the source and documentation that fabricates the Arduino. When using proprietary microcontrollers, if the manufacturers go out of business or stop producing a chip it becomes difficult to find documentation, which

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[103] Seeed Studio, "Rainbowduino LED driver platform," http://www.seeedstudio.com/depot/rainbowduino-led-driver-platform-plug-and-shine-p-371.html (accessed December 3, 2009).

[104] Media Computing Group, "LumiNet: An Organic illumination network," http://hci.rwth-aachen.de/luminet (accessed November 28, 2009).

[105] Sanguino.cc, "What Is Sanguino," http://sanguino.cc/ (accessed November 29, 2009).

makes preservation a nightmare. Similar to paints and varnishes which were undocumented, closed source chips and computer programs would need to be reverse engineered. Holistically, the difference between the artist-created tools and materials in the Renaissance and the Arduino is the aspect of open source. The open source initiative makes the tool a stronger candidate to survive with knowledge spread across many individuals, unlike the coveted paint recipes of the Renaissance kept under lock and key by the master of the studio.[106] Elkins exemplifies how a closed source mindset hurt historical artistic methods and preservation. "Painters have gone to their deathbeds without telling their secrets, and when certain ways of painting went out of fashion, the methods tended to be forgotten along with them."[107] Elkins calls attention to specific movements which sabotaged themselves:

> "…painting techniques have been lost on at least three different occasions since the middle ages. The first loss was in the fifteenth century, when Jan Van Eyck's method (…) was not passed on to enough people, and was eventually entirely forgotten. Then there was the loss of the famous Venetian technique practiced by Titian, Giorgione, Veronese, and Cima: it died slowly over several generations as painters used methods that were less and less like the original techniques. Eventually, when painters in the nineteenth century wanted to paint in the Venetian manner, they found that there was no one left to teach them and no books to consult. The third loss was the academic method developed mostly in the French Academy up to the time of the French Revolution. It was an elaborate,

[106] James Elkins, *What Painting Is,* (Routledge: London 1999), 170.

[107] "You might think that with something as well-known as oil painting, the techniques would all be written down, so that anyone could study them and try to paint like Titian or Rembrandt. But oil painting methods have always been semi-secret, like alchemical recipes." James Elkins, *What Painting Is,* (Routledge: London 1999), 170.

> exacting technique, which had grown out of the late Renaissance – but after the Revolution , when painters decided that the academies might not have been all that bad, it was too late."[108]

Documented open source works, such as the Arduino and Arduino-based artwork, can continue to live on after the art movement has passed.

Artists are makers; and through many periods it was popular for artists to make their own tools. Given this evidence, it is not surprising that artists and designers are creating their own versions of the Arduino microcontroller. Igoe comments that "There is great learning value in making your own version of a tool you use."[109] Arduino has created an easily understood product that is well documented making it easier to redesign the board as well as investigate its code, arrangement of components and functional capabilities. Designer Dario Buzzini[110] considers the knowledge of the Arduino to be ever-growing and ever-changing. "It's the incomplete nature of it, open source nature of it, it's not complete until a group of people get together and build or design the process. It is complete (much like a circuit is closed) when the people are connected with others that use it." Artist Edith Kollath[111] points out that "Once you learn the Arduino, it's not difficult to pick up other Arduino boards, it's mostly the shape that changes; the general principals stay the same."

These conclusions deduct that the Arduino microcontroller is based around learning and sharing knowledge of the tool used, rather than keeping it secret. The history

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[108] James Elkins, *What Painting Is,* (Routledge: London 1999), 170.
[109] Trevor Clarke, "The A-Z of Programming Languages: Arduino's Tom Igoe," *ComputerWorld,*October,12 2009. http://www.computerworld.com.au/article/321749/-z_programming_languages_arduino _tom_igoe? (accessed October 14, 2009).
[110] Dario Buzzini (Designer at IDEO) in discussion with the author, September 2009.
[111] Edith Kollath (Artist using the Arduino microcontroller) in discussion with the author, May 2009.

of artists' tools cannot be ignored when studying the Arduino microcontroller. While it was not uncommon for artists to make their own tools during the Renaissance era, it was often uncommon to share them broadly across any artist who aspired to use them.[112] The plethora of artist-made versions of the Arduino references a new open source era of artist tools. As artist Josh Kopel[113] states, about artists re-creating versions of the Arduino microcontroller, "In fact, there is no one thing that is an 'Arduino'. The electronics can be (and are) produced in many different forms".

4.1.3 Roles & Relationships

The usage and evolution of the Arduino has flourished on several interdisciplinary relationships. It incorporates a melting pot of cultures from many different backgrounds. Designers and artists are using microcontrollers, a tool traditionally used by engineers. Engineers are finding more ways to use their creativity that expands into the arts. Deschamps-Sonsino is aware of the varied audience the Arduino encompasses. She says "The definition of what we call art, and who owns the creative process and who is able to qualify themselves as an artist is being completely rethought." The sentiment that arts and engineering mix together, exemplified by the Arduino microcontroller, was not always the case. Limor Fried[114] created artwork in the Electrical Engineering (EE) department at MIT in 2002. Fried created a black box with wires hanging from its perimeter and installed it in a parking garage on campus as part of her EE coursework. The Assistant Dean for Student Conflict Resolution & Discipline considered Fried's artwork to

[112] Graham Paul, *Hackers & Painters*. (Cambridge: O'Reilly, 2004), 18.
[113] Josh Kopel (Artist using the Arduino microcontroller) in discussion with the author, October 2009.
[114] Limor Fried (Founder of LadyAda) in discussion with the author, August 2009.

resemble a bomb and cites Fried's relationship to art and engineering as a plausible reason why Fried's work exhibited unacceptable behavior. Whereas 'it' refers to Fried's artwork: "A note attached to it described as a Course 6 EE art project, *a questionable claim as art is not usually associated with electrical engineering.*"[115] Due to the advent of the Arduino, the typeset of engineers and hackers will continue to grow in the field of art and design. Carla Diana recognizes the role shift occurring, "We as designers face an interesting situation where there may actually be more creativity happening around us than there is inside our own offices and studios."[116]

The majority of artists and designers interviewed heard of the Arduino through word of mouth. For example, Buechley heard of it through Labrune; Vondle heard of it through Buzzini; Hartmann heard about Wiring through Bill Verplank and then the Arduino. Hartmann recalls, "I first heard about Wiring, (…) through him [Verplank]. My understanding is that Wiring, and later Arduino, were both at least indirectly influenced by Pascal's work, with Bill as the intermediary." As demonstrated by Hartmann, the majority of interviewees knew the history of the Arduino microcontroller. The social network of the Interaction Design Institute of Ivrea (IDII) grew after the program was complete. Kuniavsky asserts, "Interaction Ivrea was a highly connected group of international students and professionals who took their Arduinos all over the world". Buzzini points to the importance of the cross disciplinary relationships Arduino advocates: "…all the different permutations of the Arduino is a very good representation of what the current relationships between designers and technologists are. The only

[115] LadyAda, "Research," http://www.ladyada.net/pub/research.html (accessed January 18, 2009).
[116] Carla Diana, "How I Learned to Stop Worrying and Love the Hackers," *Interactions* 15, no. 2 (2008): 46.

reason why this type of board came about is because the reflection of the interactions and the need that was clearly manifested in design schools, and particularly Ivrea." In other words, the artists and designers are taking it upon themselves to create the tools they need in order to solve problems.

This approach does not surprise Paul Graham, "What hackers and painters have in common is that they're both makers." [117] The perception that artists don't know how to make things that function is currently in flux according to artist and Professor Kate Hartman[118]. Hartman notes that the quality of physical computing projects have gone up significantly in her classes as the Arduino is changing the concept that artists can do circuitry themselves. Collaborative work will typically be stronger and more robust due to bringing people of diverse backgrounds together. The Arduino brings together artists and engineers and uses a common language with terminology from the Arduino's modified code that they both understand. Hartman notes that Arduino makes her students multilingual. She says that when working with the Arduino, both electrical engineering and computer science are taught at the same time. Hartman cites the benefits of a common vocabulary and working knowledge of the Arduino, "You all know what is possible and what the limitations may be and you are able to have an educated conversation about your work as a whole."

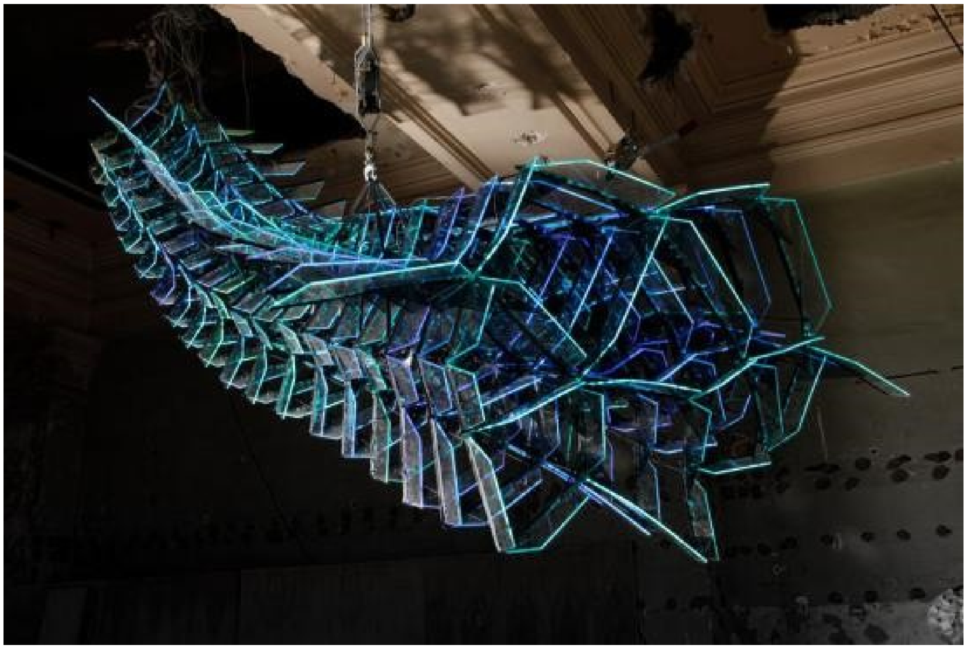
The usability of the Arduino opened up the number of artists and designers able to use a microcontroller platform. Everything on the Arduino is shareable, easy to replicate

[117] Graham Paul, *Hackers & Painters*. (Cambridge: O'Reilly, 2004), 18.
[118] Kate Hartman (Co-creator of the LilyPad Xbee) in discussion with the author, June 2009.

and easy to pass on to a friend. Jen Bove[119], an interaction designer, has had a similar experience to Hartman. Bove illuminates the condition which is so successful for prototyping: the ability to have a physical object already working when going through the steps of imagining the design. This allows for play interactions rather than abstractions. “Everyone sees the same thing, and can tweak in real time. The Arduino makes things real.”

Most versions of the Arduino were designed by more than one person within the Arduino community. Deschamps-Sonsino says she has noticed partnerships being established. For example, Buechley and the company Sparkfun have a partnership to manufacture the LilyPad. Many partnerships formed out of the Arduino between artists or designers and engineers do not happen because the artist or designer does not know how to program, but because their counterparts enjoy it more, are faster at it, or have a more detailed knowledge than they do. Hartman and Rob Faludi[120] are both artists and engineers, and both graduates of the Interactive Telecommunications Program at NYU. Together they designed the LilyPad Xbee discussed in section 4.2.2. Artists design with a full understanding of the functionalities and capabilities of the Arduino. Kuniavsky and Kurt of ThingM work in this capacity. Kuniavsky says “I know how to use an Arduino, but it is what Kurt enjoys to do and I enjoy doing the design work”. Kurt also has worked with artist Beverly Tang to create Crystal Monster, Fig 17. This relationship was more traditional, differing from Kurt’s relationship with Kuniavsky. Kurt was responsible for some of the assembly, the LED design, and all of the electronics, while Tang was the creative force.

[119] Jen Bove (Co-found of Kicker Studio) in discussion with the author, October 2009.
[120] Rob Faludi (Co-creator of the LilyPad Xbee) in discussion with the author, May 2009.



17 Beverly Tang and Tod Kurt, *Crystal Monster*, 2009, Continental Gallery, Los Angeles

Many partnerships evolve around geography. There is not a SVN[121] for physical things such as hardware, which makes it harder to collaborate in assorted geographic locations. Buechley and Sparkfun began both based in Colorado, Kurt and Kuniavsky based in San Francisco, and Hartman and Faludi were based in New York. The next section describes several evolutions modified from a lineage of designs and the partnerships it took to create different Arduino boards.

4.2 How has art and design been a catalyst to modifications on the Aduino's hardware?

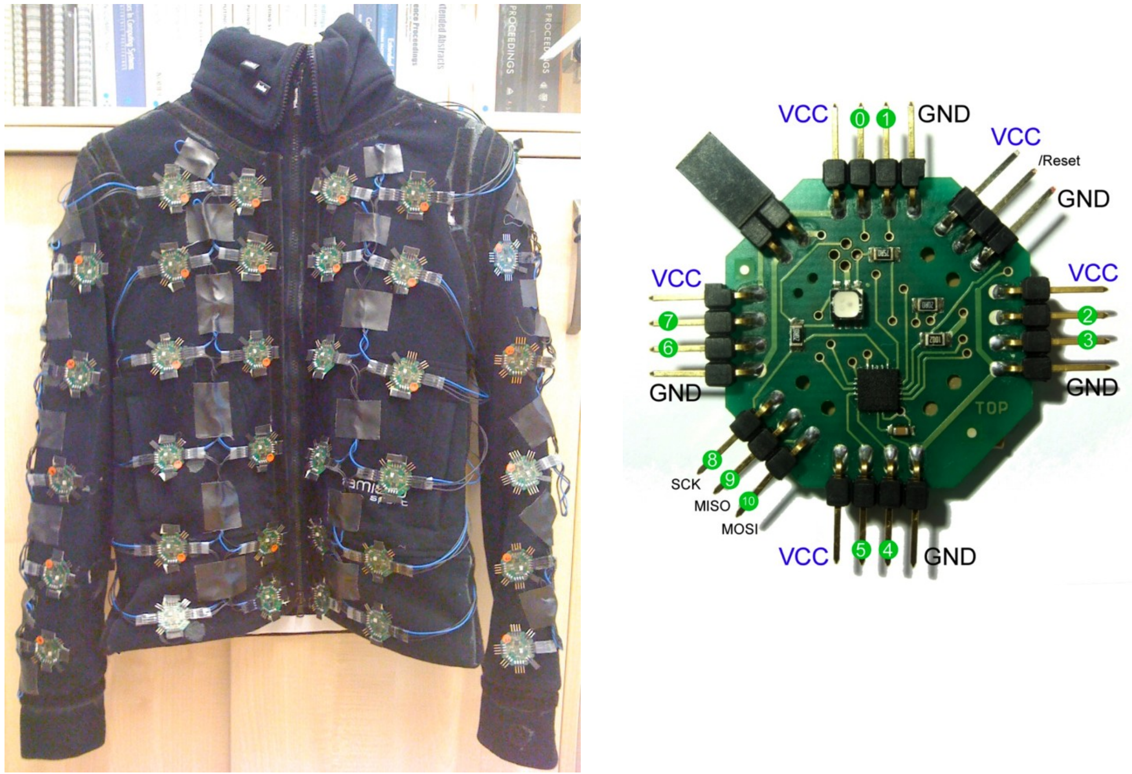
The synthesis of the usability of the Arduino, its open source element, and the relationships within the community encourage modifications to the Arduino microcontroller. Both form and function in art and design pieces are strong contenders in

[121] Subversion Network, used to store and access versions of software.

reasons why modifications are made to the Arduino microcontroller. Fifteen people interviewed modified the Arduino board for art or design purposes. Ten people modified the Arduino to create a different form or used a particular Arduino microcontroller whose form fit into their piece. Eight people modified the Arduino for functionality. The boards reviewed are significant modifications because they ended in the creation of a new Arduino board; the LilyPad Xbee, the StandAlone Arduino, and Arduino Mini. The Arduino boards listed were all modified with the impetus of art or design.

Although the above boards are prevalent within the Arduino community, the examples at hand do not stand alone. Other modifications for art and design purposes include Haque's Remote shield, discussed in Section 2.4, and his Natural Fuse[122] shield. Natural Fuse is an art project which a city-wide network of plants harness electricity consumption through the plant's carbon dioxide footprint. Hartmann created an Arduino shield to make the Phidgets microcontroller compatible with the Arduino. This shield was used with his class of interaction design students. Jan Borchers,[123] head of the Media Computing Group at RWTH Aachen University, created the LumiNet[124], Fig 18. LumiNet was made from the Arduino schematics to create wearable pixels. His board design will be included in the next official Arduino released.

[122] Haque Design + Research, "Natural Fuse," http://www.haque.co.uk/naturalfuse.php (accessed November 25, 2009).
[123] Jan Borchers (Creator of LumiNet board) in discussion with the author, November 2009.
[124] Media Computing Group, "LumiNet: An Organic illumination network," http://hci.rwth-aachen.de/luminet (accessed November 28, 2009).



18 Jan Borchers, René Bohne and Gero Herkenrath, *LumiNet Jacket* and *LumiNet*, 2008, Media Computing Group at RWTH Aachen University, Germany

4. 2.1 Form and Function

Electronic platforms are becoming more malleable to artists and designers, in particular the Arduino. At first designers had to be conscious of the size of their designs when using the Arduino microcontroller. As stated in the debates that follow, the size and shape of the Arduino's footprint have often been an issue. While at IDII, Bove originally assumed the footprint of the Arduino was an unchangeable form that was a limitation to live with. Dana Gordon[125] reflected on how designers began pushing the aesthetics of the board almost immediately, asking Banzi for different colors and smaller sized boards while at the IDII. There are currently smaller versions of the Arduino microcontroller, 4

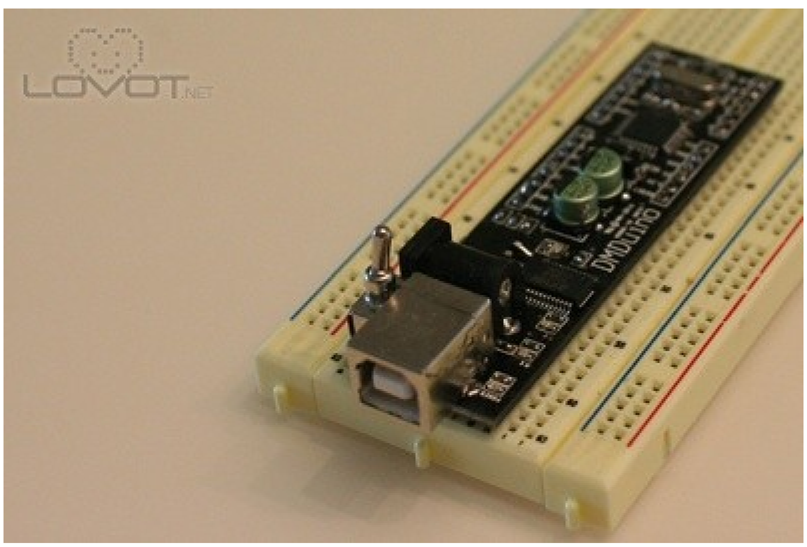
[125] Dana Gordon (Architect and designer using Arduino) in discussion with the author, August 2009.

years after the birth of the project. These include the Arduino Mini and Arduino Nano. Many current works of the interviewees were handheld. Jeff Hoefs[126] is an artist at Smart Design. Hoefs says that sometimes the Arduino Mini is too big, so he uses the same chipset for his code which allows it to be developed in the Arduino IDE. Hoefs then creates his own board designs implementing the smaller chip. Kopel comments on Arduino's square PCB shape, "it is truly a case of 'form follows manufacturing technology", however Buechley's circular LilyPad moves away from the traditional shape.

The dimensions of the Arduino microcontroller often drive the choice of which version is used. The LilyPad has different physical parameters. It has played a role in certain sized art pieces and solved a problem for several people. Kollath, the artist behind Breathing Books, Fig 28, used the LilyPad because it was flattest of the Arduino versions. The female headers on the Diecimila and the Duemilanove were too high to fit inside her pieces, which were hollowed out books. Hoefs also uses very low profile components – his general complaint was that the headers that stick up too high. Similarly, in Stern's sculpted *Vase*, the flatness of the LilyPad board was integral to her design. Another artist, Jacoon (who is a robot) and his collaborator Oskar Torres (a human) needed to use the LilyPad because it was the lightest in weight of the Arduino set. In all three cases the shape and size of the LilyPad board assisted in completing the artwork through a different form factor.

[126] Jeff Hoefs (Artist and engineer at Smart Design) in discussion with the author, September 2009.

Several people interviewed use an Arduino for prototyping their designs and altered it for the final piece, for either form or function. Hoefs, Younghui Kim[127], and Julian Bleeker[128] felt this was the major role the Arduino microcontroller played in prototyping both form and function. Hoefs modifies the shape of the electronics in his designs rather than the prototype or product being designed. Kim says she leaves the Arduino as is for prototyping and modifies it if needed for her final project. Her students use the Arduino to prototype their projects and created DMDuino[129] (an Arduino clone) in 2007 because it was difficult to get Arduino microcontrollers shipped to Korea. They chose to create a longer skinnier shape than the Arduino Duemilanove.



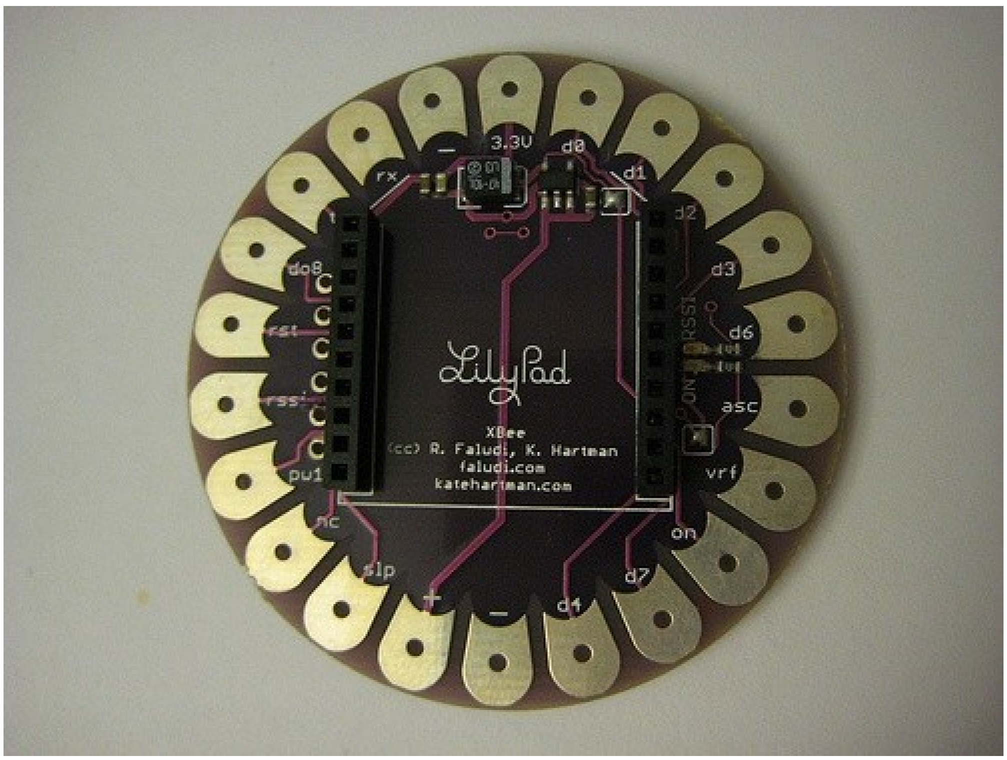
19 Hyun Hong, *DMDuino*, 2007, Digital Media Design Department in Hongik University, Korea

Bleeker says, "Once I have tested and refined a prototype with an Arduino, I often make my own PCB." The examples to follow include full board modifications for art and design purposes. Form affected the Arduino Mini, while function affected the LilyPad Xbee and the StandAlone Arduino.

[127] Younghui Kim (Artist and professor using Arduino) in discussion with the author, August 2009.
[128] Julian Bleeker (Designer using Arduino) in discussion with the author, November 2009.
[129] Hyun Hong, DMDuino (2007), http://lovot.net/entry/DMDuino-2007 (accessed March 30, 2009).

4.2.2 LilyPad Xbee

The LilyPad Xbee,[130] Fig 20, is based on the LilyPad. Fauldi and Hartman created a LilyPad Xbee board from the original design of the LilyPad. This board is not a microcontroller in itself but a breakout board for the Xbee and an addition to the LilyPad.[131] A breakout board breaks out the pins of the chip, in this case the Xbee, and makes them easier to access.



20 Kate Hartman *The LilyPad Xbee* (photograph provided by Kate Hartman)

The Xbee is a radio frequency which can wirelessly transmit data via the 802.15.4 protocol. The LilyPad Xbee paired with the LilyPad microcontroller adds more capabilities for the data transmitted to be manipulated. Fauldi and Hartman's motivation to create the LilyPad Xbee was to make performance pieces wireless. Performers (often

[130] LilyPad Xbee, http://lilypadxbee.katehartman.com/ (accessed May 13, 2009).
[131] Although, it functions without a microcontroller as well.

dancers) would get tangled in wires and choreography was sometimes limited to wire lengths. The LilyPad Xbee allows performers more freedom with their movements without the hindrance of carrying large chunky electronics glued or Velcroed in their costumes. Faludi says having wearables accommodating data from the body makes it physically and psychologically a closer space, like an extender body of data around performers.

The performance piece *Spin on the Waltz*[132], Fig 21, uses the LilyPad Xbee so that there are no prohibitive wires. Sensors were sewn into Viennese Waltz costumes and data from each sensor is transmitted wirelessly through the LilyPad Xbee. The sensors include a compass, accelerometer, a flex sensor and two soft switches, which make a connection when the dancers touched. The music in the room is controlled by the sensor data in sync with the dancers rhythm and movement. *Spin on the Waltz* was created by one of Hartman's students at Parsons, Ambreen Hussian.

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[132] Parsons, "Design + Technology 09," http://cdtproto.parsons.edu/mfadt/?q=node/25 (accessed May 25, 2009).

21 Ambreen Hussain *Spin on the Waltz* (photograph provided by Ambreen Hussain)

Hartman cited other projects using the Xbee LilyPad in her interview. These include *Squak*, *Touch by Strangers,* and *Pajama Telepresence*. Amy Koshman's *Squak*. *Squak* was a bird mask the artist wore while performing on stage to create sounds. Alexander Reader created a piece entitled *Touch by Strangers*[133], Fig 22, which also used the LilyPad Xbee. In *Touch by Strangers,* jumpsuits were embroidered with conductive fabric in the shape of hands. Performers wearing the jumpsuits, moved through the audience.

[133] Alexander Reeder, "Touched by Strangers, 2008," http://artandprogram.com/touchedbystrangers/?txt=1&img=7 (accessed December 1, 2009).

22 Alexander Reeder, *Touched by Strangers*, 2008, Manhattan (photo provided by Alexander Reeder)

When the audience touched the conductive fabrics, projected visualizations of flowers blooming were triggered. Reader also created a LilyPad Xbee driven project for partners over distance, entitled *Pajama Telepresence*.

Aside from the LilyPad Xbee, Faludi, along with Daniel Schiffmann and Igoe created an Xbee API-library for the Processing language. The Xbee API-library[134] was originally created for students at ITP who wanted wireless data to be accessed easily for their artworks, but was readily adapted by artists outside ITP.[135] Faludi says: “It's an attempt to make that data more accessible, especially for performance art projects.” The native Xbee firmware is unintuitive to work with, but the API-library creates an Xbee object over a

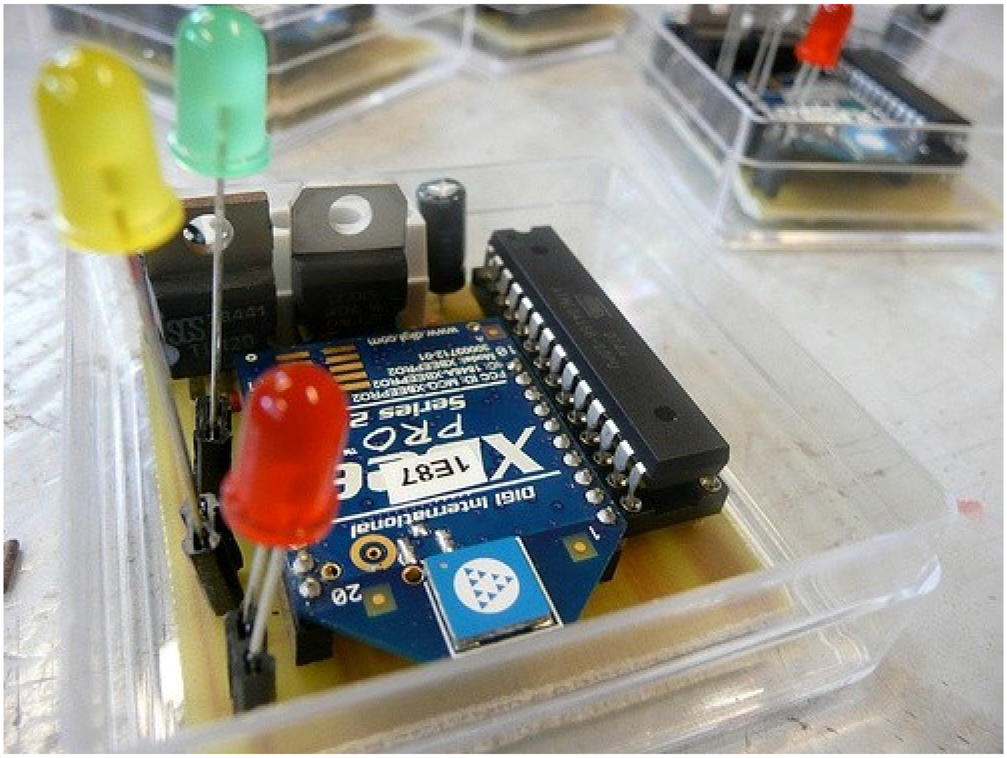
[134] Rob Faludi, “Xbee API Library for Processing,” http://www.faludi.com/code/xbee-api-library-for-processing/ (accessed May 25, 2009).
[135] See *Wind-Up Birds,* page 57.

serial interface. This library outputs analog and digital data in values easy to manipulate and understand.

4.2.3 Arduino StandAlone

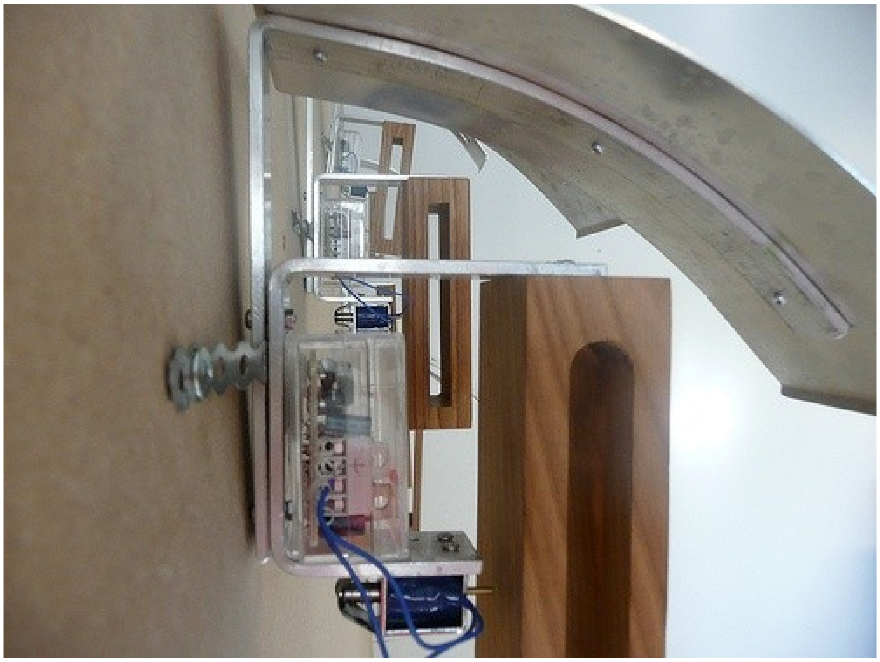
The Arduino StandAlone was a byproduct of the art piece *Wind-Up Birds*. The Arduino StandAlone is simply the chip, one capacitor, and one resistor to be powered with 3.3 volts (*Wind-Up Birds* also includes an Xbee). *Wind-Up Birds*[136] was installed in a forest near Lillehammer, Norway and needed to be energy efficient. To save energy, the *Wind-Up Birds* would sleep all night and wake up every five minutes during the day to communicate to one another through woodpecker sounds. The sleep patterns were not enough to save power, so in addition to running the Arduino chips at half speed Gilje had to modify the Arduino for his piece to achieve the specifications he needed. Together, Gilje and Jeff Mann stripped the Arduino board down to its bare components for optimal power and in the process created the Arduino StandAlone. The Arduino Standalone is also smaller than the Arduino Duemilanove.

[136] HC Giljge's Blog, "wind-up bird(s)," posted on September 4, 2008, http://hcgilje.wordpress.com/2008/09/04/wind-up-birds/ (accessed August 7, 2009).



23 HC Gilje, *Arduino-Standalone with Xbee for Wind-Up Birds,* 2007, Xbee, ATmega 168 microchip, solenoid with wooden box and metal roof, (photograph provided by: HC Gilje)

The board for the *Wind-Up Birds*, Fig 23, contained an Xbee, the ATmega 168 chip, a transistor, a diode, a solenoid, a battery, and a voltage regulator. This was a seven-component Arduino for his art installation. Fig 24 shows a side view of the *Wind-Up Birds* with the electronics exposed, the solenoid is wired below the Arduino Standalone. A metal roof was added to protect the electronics against the elements.



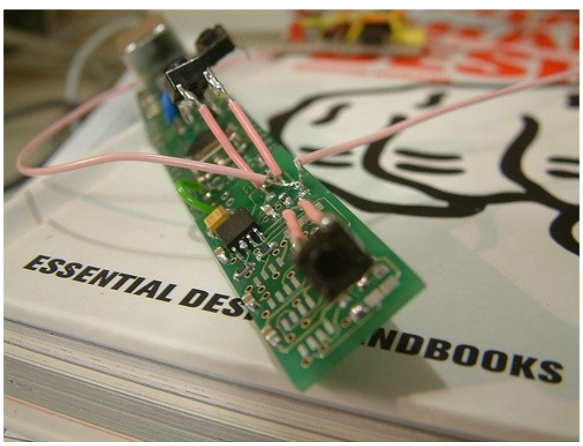
24 HC Gilje, *Wind-Up Birds*, 2007, Xbee, ATmega 168 microchip, solenoid with wooden box and metal roof, (photograph provided by: HC Gilje)

By creating the *Wind-Up Birds* and thereby the low-power Arduino StandAlone, Gilje built a new variation of the Arduino microcontroller for the arts. His code is based on the Xbee API-library.[137] The irony of the Arduino StandAlone is that it takes away the Arduino's ease of being programmed via USB, but in this instance showcased the Arduino's flexibility. Gilje had previously produced art with an AVR chip, so the abstraction that Beuchley addresses of removing the chip from the board in Section 2.2 was not an alien concept to him. Gilje said he had difficulty with AVRs and retired them for 7 or 8 years, coming back to physical computing in 2007 at an Arduino workshop taught by Igoe. This example demonstrates the importance of open source code and the Arduino community to easily reverse engineer a microcontroller, creating something with less functionality than its original.

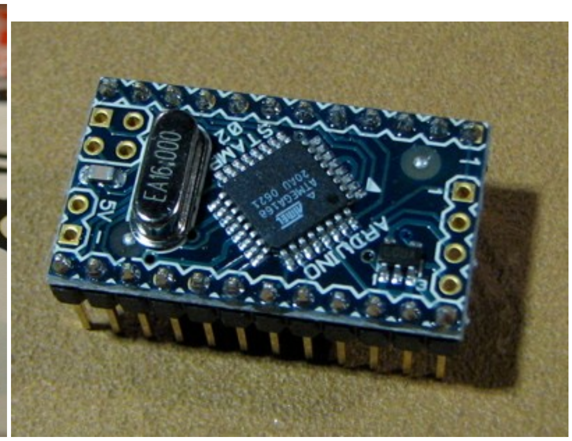
[137] See Xbee-API-library, page 54.

4.2.4 Arduino Mini

Vinay Venkatraman created an art piece with Pei Yu called *The Book Radio* at the IDII, Fig 25.[138] They reduced the Arduino in size to be small enough to fit in the spine of a book. Mellis asserts that *Book Radio* was one of the contributing factors to the Arduino mini being created, Fig 26. The book was used as a media format for listening to data from various sensors as the pages were turned. Venkatraman and Yu comment about the metaphors that prompted the *Book Radio* "We explored the common metaphors of everyday life and integrated them into a radio with the mental model of using a book[139]." Venkatraman and Pei needed to modify the Arduino to fit into a different form factor, an example of function following form.



25 Vinay Venkatraman and Pei Yu, *Book Radio microcontroller,* 2005, Arduino-based electrical design on PCB, collection of the artist, (photograph provided by Aram Armstrong)



26 Arduino, *The Arduino Mini*, 1.6 cm. x 3 cm (photograph provided by Arduino.cc)

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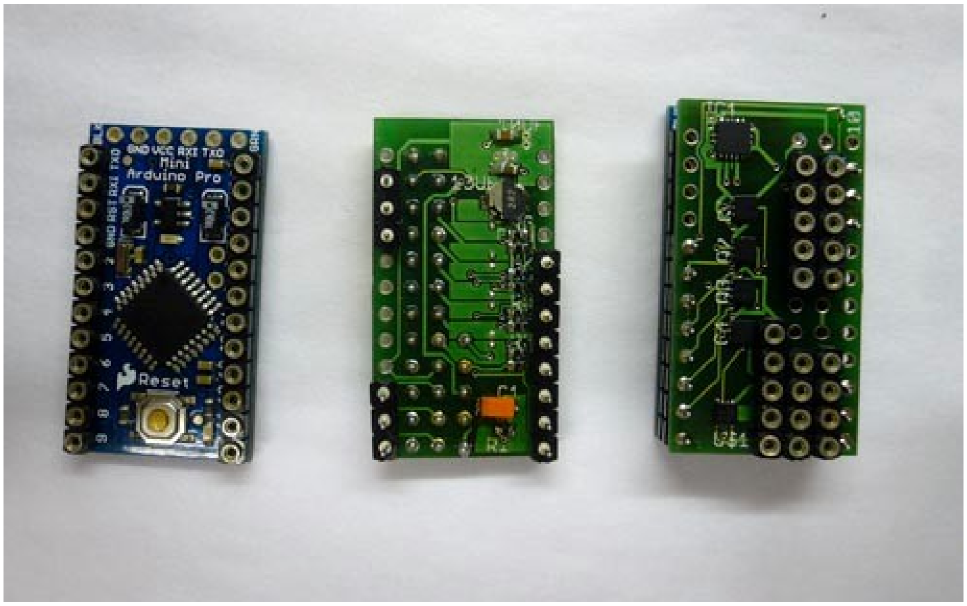
[138] "The Book Radio," http://www.idnext.com/bookradio/ (accessed November 12, 2009).
[139] Ibid.

Another way adaptations can be made to the Arduino is through shields that get placed on top of the Arduino, conversing through the I/O pins. Shields breakout the Arduinos pins and include other components to enhance Arduino's capabilities.



27 Dave Vondle, *The Arduino Mini, Arduino Mini Shield, The Arduino Mini Shield placed on top of the Arduino Mini,* 1.6 cm. x 3 cm. Photograph provided by IDEO

Vondle uses the Arduino Mini often because he creates hand held designs that require a small board. He created the Mini Shield,[140] as seen in Fig 27, because he needed to control vibrating lights and motors within his design prototypes. For each design he was rebuilding a circuit that the Arduino mini could safely plug into, due to the lights and motors pulling more current than the Arduino mini pins can source. The shield creates safe power management with the electrical current that Vondle needs. The shield enables him to "stop re-inventing the wheel each time and allow for faster prototyping within design".

[140] IDEO Labs Blog. *Arduino Mini Shield for Small Prototypes.* Posted by Dave Vondle. http://labs.ideo.com/2009/08/10/arduino-mini-shield-for-small-prototypes/ (accessed August 8, 2009).

The significance that artists and designers are modifying the Arduino means their understanding is deep enough to manipulate the behavior and design of this microcontroller in both its functionality and its footprint. Artists and designers readily modify the board components and footprint to fit within the confines of the piece. The Arduino microcontroller shows clarity in its process and purpose and is a flexible design. Just as Antonelli's statement of transparency in process and design expresses, "Modern design is about showing clarity of process and purpose, and the best among them relied on their post-modern flexibility to update the positive qualities of modern design and to express the most contemporary visual culture."[141] Artists were able to keep the original form of their piece they designed without modifying it for the function of the electronics. The modified Arduino boards when documented or sold are used by many more people, creating an additional economic award for artists and designers to open source their Arduino-based microcontroller. This type of payback is unique to the open source market.

4.3 How does the Ardiuno shape creative practice in art?

Twelve people felt the Arduino enhanced their creative process, or accredited the Arduino to magnifying their ingenuity. The creative process is the process which creative insights are explained within preparation, incubation, intimation, illumination, and verification.[142] Creativity can also be affected through iterations in rapid prototyping.[143] Sixty percent of people interviewed used the Arduino for prototyping iterations in the design stages of their work. Bove, a designer of websites, consumer electronics,

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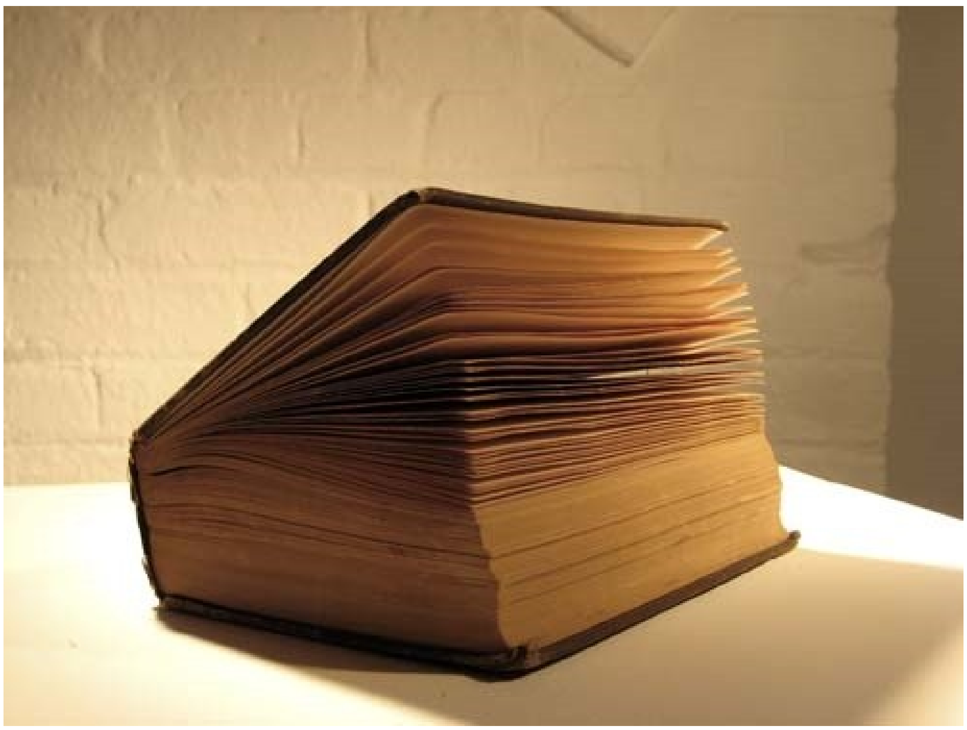
[141] Paola Antonelli. Forward of *Design By Numbers* by John Maeda. First MIT Press: Cambridge, MA, 1999.

[142] Graham Wallas, *Art of Thought* (New York, Harcourt, Brace and Company 1926).

[143] Steven Dow, Kate Heddleston, Scott Klemmer, "The Efficacy of Prototyping Under Time Constraints," (accepted paper, ACM Creativity & Cognition Conference, Berkeley, CA, October 27-30, 2009).

appliances, devices, and environments affirmed “It's helped me think about product behaviors with more tangibility. It breaks things down in a way that they can be prototyped.” Interviewees reported two aspects which enhanced the creative process, usability and time. Due to the Arduino microcontroller usability, it decreased the amount of time spent on electronics for artists and designers. Interviewees conjectured that the time saved allowed for more creative thought and further iterations.

The Arduino microcontroller has expanded the creative process of many artists and designers because of its easy to use platform prompting more time for creativity rather than analyzing functionalities. Between designers, artists and engineers almost everyone had a different answer for ways in which the Arduino may have affected their creative process. Designers in particular felt creativity existed independent of tools and materials, but the innovation of the Arduino allowed capabilities within electronics to be expanded. This occurrence allows artists and designers to have more control of their tools and materials, including the option to create their own. These individuals mentioned specific functionalities which were less complex to program via the Arduino microcontroller and therefore they were allotted more time for creative thought processes. Haque refers to the learning curve of other devices as torture and asserts, “I really appreciate the way that working with Arduinos enables me to avoid the torture and just get down to building.” Hoefs explained the example of i2c in his interview. I^2c is an interface for busing data. The thought process when dealing with an i^2c library is different than thinking through the act of pulling raw i^2c data from the chip. Knowledge of the i^2c process behind a sensor is not necessary to program a sensor when using the library created for the Arduino microcontroller. Instead, an object in the code tells the sensor what to do. The low level interface protocol does not need to be understood, and can be replaced by thinking about what the sensors will do. Artist Kollath had a similar manifestation with the capabilities of the LilyPad Arduino. Understanding what the Arduino was in the LilyPad form factor, she created her *Breathing Books*, Fig 28, which then grew into a *Breathing Room*. The ease of using the Arduino gave her the confidence to learn electronics. It enabled her to add the element of movement to her work.



28 Edith Kollath, *Breathing Books,*2008, LilyPad Arduino adapted with h bridge and servo motors inside a book, in collection of the artist *(*photograph provided by: NYC Resistor, NY)

As Kollath discovered how to control the element of movement in her artwork, Buzzini asserted the Arduino allows him to control another dimension of design, the element of time and speed in tangible objects and interaction. He says that "Arduino definitely helps designers think in a different way, to approach a challenge in a different way. It helps technologists be more visual and communicative. It plays a different approach in their code and their work." Artist John Bennett agrees with Buzzini, "Arduino, as a tool set, makes crazy ideas possible. In that aspect it's caused me to come up with installation ideas that normally I wouldn't have thought possible”. Some engineers responded that the Arduino made them realize they could be creative[144]. Labrune stated that artists brought creativity to the Arduino and to technical people. “Artists bring a new perspective to technology and make the Arduino more creative.”

Besides the ease of creating function pieces, time management was remarked to be a useful result of the Arduino microcontroller. Eight people spoke of time as an additional factor that impacts their creative process in addition to the Arduino’s usability. Fabian Winkler,[145] an artist and professor says, “The Arduino board has saved me development time that I was able to use for other creative processes/decisions”. It also helped reduce the prototyping cycle, so there was additional time for more designs. Vondle claims that it “…enhances the creative process by making it easier to go from concept to execution. Sketching in hardware as the Arduino allows, I can sit down with the board, search for code on the Internet, get it up and working, and test it so you know the behavior works and you can do it in three hours versus three days. That allows you to iterate through concepts a lot faster.” Vondle acquired a building with a big glass block wall that looked like pixel cubes to him. He conceptualized a life size *Pong* game on the surface, but creating his own boards was too labor and time intensive. When he encountered the BlinkM's,[146] Fig 29, he realized that was what he needed to create his wall in a time efficient manner.

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[144] One engineer insisted they had no creative process – which prompted an alteration in vocabulary for the interview questions. The question shifted to ‘Is there anything you attribute the Arduino to for enhancing your creative process?’ to add ‘ingenuity or creative process’.
[145] Fabian Winkler (Artist and professor at Purdue University) in discussion with the author, October 2009.
[146] ThingM, “BlinkM, the smart LED,” http://thingm.com/products/blinkm

29 Tod Kurt and Mike Kuniavshy, *BlinkM*,2009 (photograph provided by todbot)

By saving time, whether in the creating phase, testing phase, or conceptual phase, each portion builds on creativity, and the time saved allows for more creativity.

Aside from usability of the Arduino's functionality and time enhancing creativity, sixty percent of interviewees agreed that having a common platform and community with a common language, as the Arduino does, helps inspire them. Stern added that her creativity is expanded when she gets inspired from other projects happening within the Arduino community. Although the Arduino microcontroller is not directly responsible for creativity, creativity is a provoked side effect when designing with the Arduino.

5. Conclusions

The semantics in which the Arduino is used by artists and designers points to its success and growth within its intended audience. The findings situate the Arduino microcontroller differently than former art and design tools. The most significant finding shows that both form and function in art and design pieces are strong contenders in reasons why modifications are made to the Arduino microcontroller. The usability, community and open source initiative of the Arduino microcontroller empower artists and designers to manipulate their tool and iterate new versions of the Arduino microcontroller. The LilyPad Xbee and the StandAlone are examples of functional modifications. *Book Radio* was modified for its physical footprint and later morphed into the Arduino Mini. Both form and function were incentives for the creation of the LilyPad Arduino. The Arduino microcontroller also assisted in the creative process, largely through time and functionality. It is a tool that caters to experimentation and quick prototyping due to the time allotment saved from having an attainable device. Inspiration benefits from a community-driven tool. The Arduino microcontroller is also a tool that is ever-changing, both by the Arduino community and from further development of the Arduino team. As Igoe states in his interview with *Computer World*, if something needs to be altered on the Arduino, the change happens: "I don't think there is an answer to "what would you do differently", because when we encounter something we'd do differently, we make a change."[147]

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[147] Trevor Clarke. ComputerWorld The A-Z of Programming Languages: Arduino's Tom Igoe 12 October, 2009.
http://www.computerworld.com.au/article/321749/-z_programming_languages_arduino_tom_igoe?

The consideration that the Arduino microcontroller is malleable by a non-technical audience is important to the future new media art and the field of design. Kollath maintains, “We are adjusting to a new medium, and a historical movement of a revolution in art using a new technology”. The medium is the Arduino microcontroller, and the movement is one of open source hardware. Microcontrollers in art may be a difficult new concept to grasp as art and technology collide once again. However, the Arduino is an open source, cross-disciplinary tool, which makes it rich in its knowledge and language. To quote Shanken on the topic of cross-disciplinary frontiers, “… to understand the evolving relationship between contemporary art, science, and technology, one must grapple with the complex processes and products that sustain and result from collaborative research.”[148]

The open source hardware movement has stirred the art and design communities with the Arduino microcontroller. Speculations of where designers and artists will find future flexible, accessible and adapt them to open source tools was summarized by Labrune, Buechly and Zambetti. Labrune asks, “What data will influence other projects? Will the heuristics of the future become a conversation? What other open source platforms will artists use as their tool, such as the BUG of Bug Labs?” Buechley’s current work is with paper circuits, which blends electronics with traditional forms of painting and drawing. She utilizes non-traditional electronic materials, such as conductive thread and conductive ink, as she jokes: “conductive fabrics aren’t just for the military anymore!” Zambetti says the future of Arduino can also expand in terms of its

[148] Edward A. Shanken. Concluding Reflections: Art History, Interdisciplinary Collaboration, and the Interpretation of Hybrid Forms. In *Media Art Histories*. P. 65

community, “Making more languages available to Arduino is also important for the future of the project, for example, MAX/MSP, opens up another user group to Arduino”.

The history of the Arduino microcontroller within art and design has already begun. The Arduino microcontroller affects the creative process, is attainable as a malleable art and design platform, and well designed for its intended audience. It will surely flourish through its various communities as it gets molded and transformed into descendant boards resulting from artworks and designed constructions.

Appendix A: List of Figures

Jan Borchers, René Bohne and Gero Herkenrath, *LumiNet Jacket* and *LumiNet*, 2008, Media Computing Group at RWTH Aachen University, Germany

Hyun Hong, *DMDuino*, 2007, Digital Media Design Department in Hongik University, Korea

Kate Hartman *The LilyPad Xbee* (photograph provided by Kate Hartman)

Ambreen Hussain *Spin on the Waltz* (photograph provided by Ambreen Hussain)

Alexander Reeder, *Touched by Strangers*, 2008, Manhattan (photo provided by Alexander Reeder)

HC Gilje, *Arduino-Standalone with Xbee for Wind-Up Birds,* 2007, Xbee, ATmega 168 microchip, solenoid with wooden box and metal roof, (photograph provided by: HC Gilje)

HC Gilje, *Wind-Up Birds*, 2007, Xbee, ATmega 168 microchip, solenoid with wooden box and metal roof, (photograph provided by: HC Gilje)

Vinay Venkatraman and Pei Yu, *Book Radio microcontroller,* 2005, Arduino-based electrical design on PCB, collection of the artist (photograph provided by Aram Armstrong)

Arduino, *The Arduino Mini*, 1.6 cm. x 3 cm. (photograph provided by Arduino.cc)

Dave Vondle*, The Arduino Mini, Arduino Mini Shield, The Arduino Mini Shield placed on top of the Arduino Mini,* 1.6 cm. x 3 cm. Photograph provided by IDEO

Edith Kollath, *Breathing Books*,2008, LilyPad Arduino adapted with h bridge and servo motors inside a book, in collection of the artist (photograph provided by: NYC Resistor, NY)

Tod Kurt and Mike Kuniavshy, *BlinkM*,2009 (photograph provided by todbot)

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