Investigating 3E-materials at Agbogbloshie in Accra, Ghana

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***Abstract*—The product life cycles of electrical appliances and electronic devices impact society and the environment, given the hazardous portion present in their materials flow. Scrapping as an industry serves to decommission end-of-life (EOL) equipment, linking materials processing and recovery activities with recycling, but must be controlled against adverse environmental and human health safety factors. This work tracks an on-going effort—the Agbogbloshie Makerspace Platform (AMP)—to use participatory design methods to upgrade capabilities of the scrap, recycling and maker community located at Agbogbloshie in Accra, Ghana through co-creation of technology. The authors explain AMP's aim to reconceptualize Waste Electrical and Electronic Equipment (WEEE or e-waste) as Electrical and Electronic Equipment (EEE or 3E): not as waste, but as inter-manipulable assemblages of 3E-materials. AMP seeks to employ a hands-on Makers and Development approach (M&D) as a collaborative process to drive interclass innovation by co-designing and fabricating a makerspace, or open community workshop and lab, and networking e-waste and scrap recyclers starting at Agbogbloshie with students and recent graduates in Science, Technology, Engineering, Arts and Mathematics or STEAM fields. The investigation at Agbogbloshie over a period of 24 months suggests opportunities for utilizing participatory design to leverage waste management and 3E-materials processing across informal sector recycling ecosystems as inputs for popular prototyping, i.e. peer-to-peer digital fabrication and distributed manufacturing.**

Keywords—participatory design; e-waste; scrap; informal sector; 3E-materials; STEAM; Ghana—Agbogbloshie.

I. INTRODUCTION

Design issues spanning planned obsolescence, moral aspects surrounding conflict minerals, the environmental impact of electronic lifestyles, the ecological footprint of microchips and the concomitant hazards of recycling electronic devices and systems are increasingly acknowledged as engineering problems with a human social dimension, alongside natural and technological constraints. The below probes how participatory design can serve as action-oriented interface between engineering and education, triangulating integrated approaches to research and development of "technology-enabled innovations" [1] that engage equilibrium between parties that benefit directly and those most affected.

A. From Bauhaus to Fab Lab

We can see in the Bauhaus the ancestor of the Fab Lab. The influential Bauhaus school, operating in Germany 1919-1933, devised an integrated approach to the arts, teaching fine and applied arts concurrently. Key Bauhaus protagonists emigrated world-wide, assisting aspects of this hybrid course in aesthetics and craftsmanship to become standard modern design education. The Bauhaus approach centered on the pedagogy of the workshop: "The 'workshop' was the structural basis of the Bauhaus method of teaching. Eliminating the academic connotation of the term 'professor,' Gropius had the teachers called 'masters' and the students called 'apprentices' and 'journeymen,' to put them into the context of real world trades. Because there were no qualified instructors for such a new style of teaching, each workshop was shared by two teachers: a 'workshop master,' typically a craftsman skilled in manual skills, materials, and production; and a 'master of form,' generally a fine artist who would try to stimulate creative thinking." [2]

The *Vorkurs* foundation course of the Bauhaus school emphasized a design philosophy that viewed all forms of art and design as interrelated and design as total and universal: communication and graphic design, product, furniture and industrial design are not disparate from architecture, but rather its summation. Students learned by working and reworking a range of materials, discovering line and color, shape, space and structure through experiential learning, i.e. by making. Thus the approach of the Bauhaus "school of building" sought to develop within students conceptual tools and manual skills, based on an understanding of nature and technology, that enable them to manipulate their environment optimally.

More recently, Fab Labs—championed by MIT's Center for Bits and Atoms—present an alternative model for hands-on learning in concert with digital tools. Situated within a broader discourse around "making", Fab Labs provide a set of equipment for digital fabrication together with a user community that assists and supports its members to make things that they want to make, in the process not only learning but also developing new technology. Hundreds of Fab Labs now form a global network that proponents argue is a platform for innovation, because it connects users across labs and with the tools to rapid prototype their own ideas at low cost, themselves. [3,4] Fab Labs were conceived as a research

Pilot project of the Agbogbloshie Makerspace Platform was made possible in part by funding support from the Rockefeller Foundation.

project to encourage the democratization of technology; make Fab Labs accessible to as broad a cross-section of society as possible, thereby enabling access to digital tools independent of economic background. Indeed, Fab Labs as a collaborative project are viewed as a model for ICT development that seeks to empower people to impact complex global conditions through personal fabrication. [5] The first Fab Lab beyond MIT to come online under the Fab charter is at the Takoradi Technical Institute, which reportedly "opened to a wide range of public users, 'from street children to tribal chiefs.'" [6]

Fab Labs are a general-purpose workshop designed to make anyone a maker. Building on computer literacy, Fab Labs integrate digital, mechanical and electronic design all geared toward personal fabrication. Their standard set of tools are relatively technologically-advanced—encompassing design, fabrication, testing and debugging, monitoring and analysis, and documentation—allowing users to achieve production of sophisticated prototypes. At once a digitally networked and non-hierarchical workshop structure, Fab Labs replace Bauhaus' interdisciplinary but elevated "masters" with a horizontal pool of "makers": design process remains linked fundamentally to making, but all participants co-create together by sharing skills and expertise.

B. Smart cities and the Internet of Things

Planned obsolescence refers to the engineering design objective of specifying consumer products to artificially short life cycles, in order to ensure consumer demand over time, and today is widely regarded as problematic viz. increasing consumerism at the expense of environmental sustainability. While the discourse of pervasive and ubiquitous computing of a decade ago already established that rise of electronics use poses risks to sustainable development [7], the same applies under the ascendant narrative of smart cities and the Internet of Things (IoT). Smart city models of urban development prescribe industry-led solutions that exploit digital networks to encode and control large-scale human settlements, while IoT is a regime in which all devices become internet-enabled and sensor technology allows a greater degree of real-time decision-making to be handled by machines instead of people.

Recent suggestions that a smart cities model targeting wicked problems may be a more appropriate method for applying computation to city-making than urban cybernetics [8] follow alongside the prediction that over next several decades, more than 1 billion additional urban-dwellers will live in Africa and Asia; how will the smart cities of these territories be structured: "Smart city discourse is largely looking into the immediate future and at places already known and functioning. How and whether the scholarly community contributes to the evolving discussions of the city of the future will rest on our ability to produce solid, detailed and effective empirical studies of this process of urban transformation." [9]

The smart cities and IoT nexus trends to increased chipset densities within urban networks. Agbogbloshie represents on the other end an urban territory on register with "Temporary Autonomous Zone" (T.A.Z.) [10]—areas of alternate status, here proscribed by government and agreement as semi-legal, semi-permanent and semi-autonomous; but equally imbued with ingenuity and underground *azaa* [11,12,13,14,15]—a place where human hazards of 3E-materials are localized disproportionately to tangible benefits.

II. 3E-MATERIALS

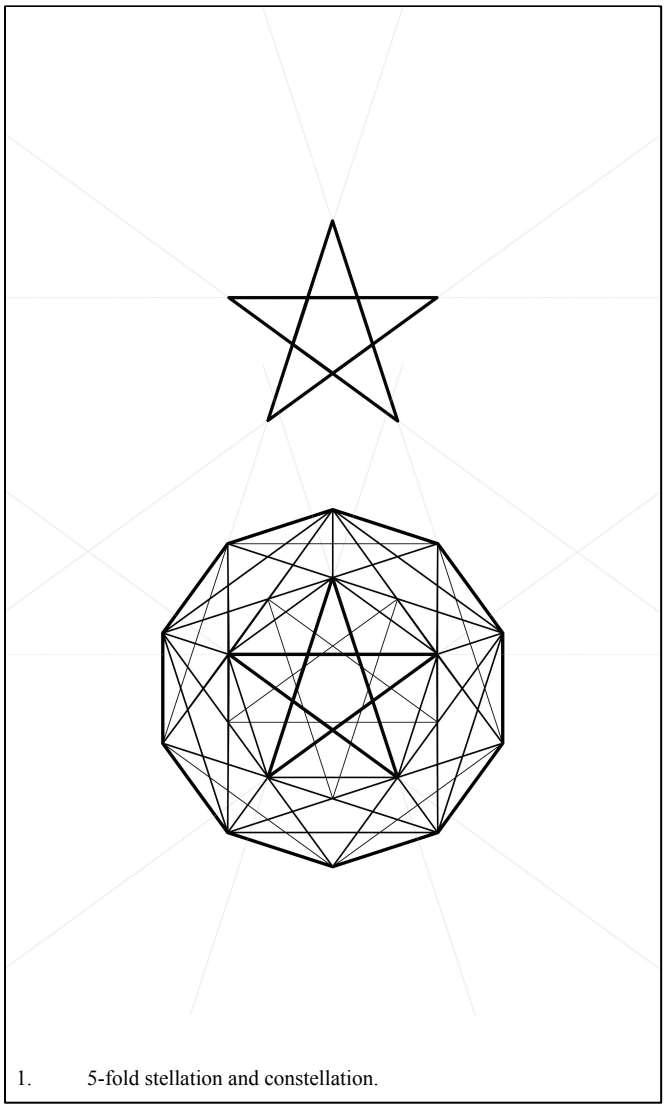
A. Recycling e-scrap

Waste Electrical and Electronic Equipment (WEEE, e-waste) and the set of materials typically used to form and assemble them (EEE- or 3E-materials as opposed to e-materials, i.e. semiconducting electronic materials) may contain hazardous portions including heavy metals, polybrominated flame retardants, and polymers such as polyvinyl chloride (PVC), polyurethane (PUR) that can produce Persistent Organic Pollutants (POPs) when burned. [16,17,18] The nature of many of these toxins is such that they bioaccumulate in living systems rather than biodegrade. Exposure to persistant bioaccumulative and toxic chemicals is an on-going risk at Agbogbloshie, an informal sector scrapyard and recycling center in Accra, Ghana and the site of the "Makers and Development" (M&D) exploration detailed in this design investigation. [19,20]

The Agbogbloshie scrapyard, located behind the Agbogbloshie Market, Onion Market and formerly, Yam Market, on Abose-Okai Road in Accra hosts dismantling, sorting and processing activities across a range of scrap types, from aeronautical, automotive, electronic (e-scrap), domestic and household waste to glass, metal, and plastics. An estimated 3000-6000 persons working in the e-scrap trade [21] some part-time or seasonally, dismantle and/or process a spectrum of items each year—from batteries, fans, irons, toasters, microwaves, washing machines, fridges, televisions, desktop computers, laptops and mobile phones to bicycles, cars, trucks, trailers, heavy machines, aircraft and mining equipment, transformers, telecommunications masts and network routers—forwarding scrap onward to steelworks, copper refineries and specialized recycling industries.

The Agbogbloshie scrapyard and recycling center has been discussed both in scientific literature and the popular media, typically depicted as a highly polluting e-waste dump. Today's contaminated wetland landscape results from multiple decades as Ghana's largest e-waste and scrap processing zone. Despite successive interventions of government and nongovernmental organizations, current and former dismantling and processing activities occurrent at Agbogloshie continue to contribute to overly high concentrations of toxic or hazardous materials measured across the Agbogbloshie environs [22,23,24]. Consequently, consistent with informal sector recycling generally, some "low-tech" manual techniques of dismantling and disassembly in use at Agbogbloshie adversely impact the environment, worker and public health. Recent studies estimate that 40-80,000 people are resident in Agbogbloshie per annum (changing population), extensive to the Old Fadama slum community. [25]

However, while Agbogbloshie is a high profile environmental emergency, it is only the center—a "waste hub" [26] not the extent—of the manu-digital urban workspace of e-waste recycling carried out "by hand" in the Accra-Tema urban areas. Increasingly, the scrap trade in Accra is decentralizing, forming a distributed network of storage and processing across urban territories. How can we better understand—perceive—both the environmental loads of waste management, in particular e-waste processing, as well as the opportunities for utilizing this waste stream in novel ways?



1. 5-fold stellation and constellation.

B. Urban innovation

In response to this question and in order to conduct a case study on inducing urban innovation, the authors proposed a general vision set for the project from the outset: Transform the Agbogbloshie scrapyard, materials processing and recycling zone into a network for digital fabrication and distributed manufacturing (makerspace platform). The immediate next question, taken in response to the site, was, "How to change Agbogbloshie through involving current occupants not as test subjects and data points, but as agents?" We recognized early on that as evidenced by the number of people and current commercial levels, despite high levels of pollution, there is real economic and environmental potential at Agbogbloshie. Is it possible to unpack or begin to model this SET of activities, so as to re-deploy a motorized form of Agbogbloshie-modeled micro-industrial ecosystems for broader application?

C. Stellate design

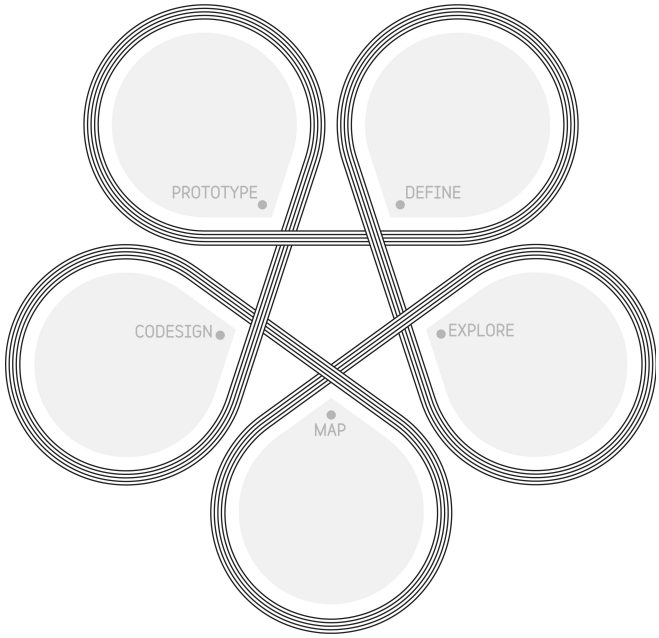
The participatory design method employed in this investigation is characterized this text herein as stellate design. The coupled principle behind design stellation is that innovation radiates and clusters innovate; hence, stellation and constellation are an interoperative mode for inducing innovation (Fig. 1). A standard procedure is introduced in the form of a five-fold orbital or innovation star, which proceeds iteratively through overlapping and concurrent steps: define; explore; map; co-design; prototype (Fig. 2). This method therefore enables each revolution of steps to include making a prototype; this is referred to below as part of M&D process.

D. Interclass innovation

Potential for "interclass innovation" derives from integrating the skills and productive capacity of two classes of youth that typically remain decoupled under conventional frameworks of social behavior, e.g. in Ghana. Stellate innovation requires constellation, or the clustering of normally disparate entities, for activation. Hence, pursuant to project objectives AMP seeks to generate hybrid social networks that link across class by assembling young people from different class backgrounds (as well as ethnicity and religion) into a shared design process.

The hypothesis behind this is that bringing recyclers and scrap dealers from the informal sector, who possess practical knowledge regarding both properties of 3E-materials and resale value of parts and portions recovered from WEEE, together with undergraduate and graduate students and young professionals in STEAM fields (Science, Technology, Engineering, Arts and Mathematics), who have a strong technical education skewed toward theory, can create opportunities to develop sustainable social innovation in Africa by integrating engineering with participatory design. Over a period of 24 months to plan, design and fabricate a makerspace (e.g. open community lab cum workshop) at Agbogbloshie, one of the main objectives throughout the process was to target "interclass innovation" through "popular prototyping" or making together (DIT/DIY, i.e. Do-It-Together instead of Do-It-Yourself): working to bridge competencies and build a hybrid culture of makers that aspires to share knowledge regardless of background.

Over 1000 Ghana youth in STEAM (Science, Technology, Engineering, Arts and Mathematics) backgrounds and informal scrap trade and maker communities have participated in the AMP design research process, in dialog with Dr. Abbas' students at l'École Spéciale d'Architecture in Paris, France. Tools prototyped and/or assembled and user-tested include Hal Watt's and Matt Batchelor's e-Cycle machine, a cycle-powered copper shredder for fine copper wiring (via Recyhub); a quadcopter drone using recycled plastics for the body (with Samuel Frimpong, Creativity Group-KNUST and Ivan Gayton via Recyhub); optical and laser spectroscopes; mini-kiln for melting plastics; spraying machine powered by fridge compressor; "JerryClan" recycled computers in jerrycans ("Jerrytop" computers, with Wɔɛlab hackerspace in Lomé); gas masks; a "spacesuit" utility vest; and the makerspace itself, a prefabricated semi-octet-truss modular structural system with kinetic bifold hangar portals, and which incorporates recycled materials (light-gauge steel sections made in Ghana with part recycled Agbogbloshie scrap), repurposed flooring out of rubber conveyor belts from mining industry; rubber car tires as permanent formwork for concrete, packed stone aggregate foundation pads; glass fridge display doors repurposed as windows; used truck tarpaulin; as well as electrical parts and electronic components recovered from non-functioning computers; and the AMP tool set generally.



2. 5-fold design stellation (innovation star): Define, Explore, Map, Codesign, Prototype

E. Makers and Development (M&D)

Whereas R&D (Research and Development) denotes government or corporate investment in knowledge so as to apply it to innovation, M&D is peer-to-peer and targets capacity-building: a codesign process centered around popular prototyping and testing. Simultaneously iterative, experiential and collaborative, M&D connects an open community of participants as makers and lets the process of making help generate creative solutions to development challenges.

M&D derives as a term from a series of design research seminars conducted at l'École Spéciale d'Architecture (2013-2015), which opened students to participation in a group project to challenge the consequences of technological dependence by remaking Agbogbloshie T.A.Z. conceptually: proposing tools to better equip the dynamic territory that operates outside the bounds, hosting technology's unmaking and reconstitution. Spaces of unmaking inherently anticipate spaces of remaking; in Agbogbloshie at the end and restart of product life cycles the mantra reduce, re-use, repair, recycle forges its own logic. M&D operates via emphasis on making: each loop of conceptual iteration necessitates another prototype, so participants inherently discover knowledge through the making process. In the case of AMP, the community of makers includes a diverse collection of individuals working not only in Agbogbloshie (e.g. computer repair and refurbishment workshops, small-scale aluminum smelters) but also situated adjacent in the Accra Timber Market (e.g. the carpentry, metalworking, tinsmithy and equipment manufacturers) and distributed further afield (roadside electronics repairers, mechanics, welders, glaziers, furniture craftsmen, seamstresses and tailors city-wide) who make and repair items for a living.

Fieldwork in Agbogbloshie has shown precedence of apprenticeship models within organization of loose workshop structures sited in fixed locations, e.g. clusters of containers and sheds, as well as mobile satellite locations, e.g. temporary burn sites or panurban collection routes traversed by hand cart "trucks" pulled solo or in tandem. AMP seeks to build on top of existing apprenticeship models at Agbogbloshie to stimulate creative thinking and boost craftsmanship through workshop-based manu-digital making.

Making a makerspace: The Agbogbloshie Makerspace Platform (AMP) is a collaborative project built around the theme of upgrading quality of life and environment at Agbogbloshie. AMP seeks to create an alternate convention that links Agbogbloshie's e-waste, scrap & recycling industry with the technical know-how and social entrepreneurial framework to partner globally and remake built, product and virtual reality environments, over time. The approach is to design and build locally a knowledge database and set of tools for e-waste processing and digital fabrication. The intention is to empower informal sector e-waste workers and their peer groups to help green the community's current recycling practices, toward the goal of stabilizing and then rehabilitating the environment of Agbogbloshie.

III. EXPERIMENTAL

The AMP design investigation follows the five-fold orbitals of the innovation star that organize a flexible, data-driven and action-oriented design process for piloting urban innovation. This stellate design model infers that innovation depends on finding additional information, via setting new frames of reference and then experiencing through them (process definition). Exploring thereby is a process of discovering new data bytes of information about SET (Socio~, Eco~ and Techno~) logics of place by scanning. Mapping refers rather to ordering acquired data SETs to render their composite topography more comprehensible. Codesign is both co- design (i.e. together) and design of code, or design as coding. M&D then encapsulates formulation of design code and prototyping tools. Stellate design occurs via a five-fold simultaneous series of operations: Define, Explore, Map, Codesign and Prototype. In overview:

1) Define: *Understand the focus zone and clarify a SET (Socio~, Eco~ and Techno~) logics of place; an action-orientation relative to urban environment; definition is an action plan with set of thematic questions to explore.*

2) Explore: *Unearth new data SET; discovered via walkabouts and meet-and-greets on the ground, i.e. field trips, surveys and interviews. Informed by the concept of stigmergy, encode and decode information from environment through interaction; similarly, gain knowledge of environment.* [27]

3) Map: *Order and navigate data collected to generate new information spaces. Maps are generative apparati; embedded in the DNA of maps are cues to code to design viable innovative urban interventions.*

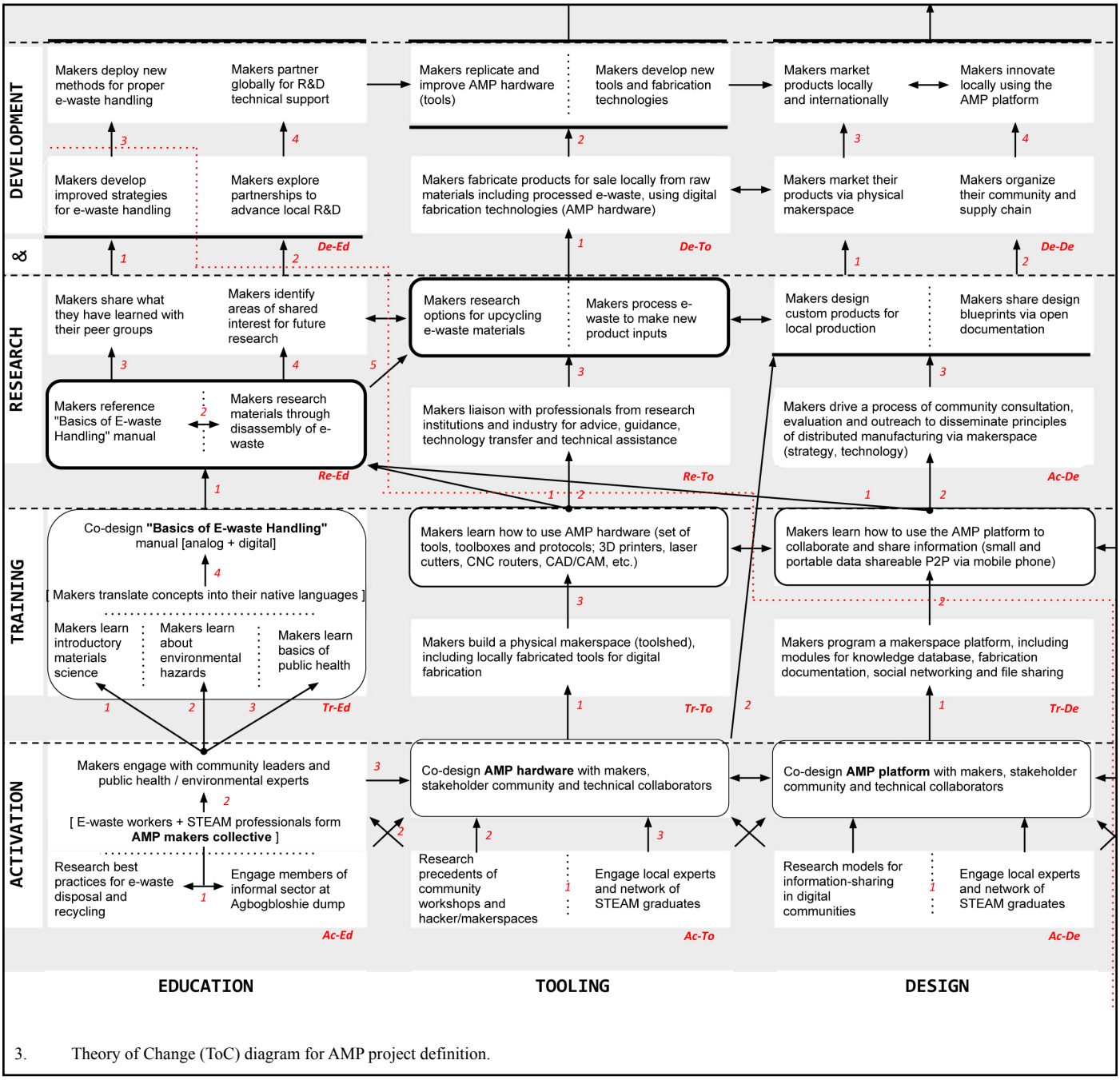
4) Codesign: *Engineering from existing processes revised code for ordering urban environments through information, whereby information is considered as transformative. Collaborative community workshops require codesign to share vision and conversation.*

5) Prototype: *To bring to life urban innovation, one needs to prototype a series of seed interventions (for example, the spacecraft and the plastic brick).*

(1) Define: SET frames of reference

The top-level action-orientation for the research is, as stated above, to "Transform the Agbogbloshie scrapyard, materials processing and recycling zone into a network for digital fabrication and distributed manufacturing (makerspace platform)." The authors thus set out to determine frames of reference for the design investigation by posing a series of reciprocal questions: How does the informal sector practice of material processing in Agbogbloshie operate? What do the various actors involved in e-waste processing understand about the full extent of their trade and its environmental consequences? How might makers come together to advance the technology at their disposal and thereby create new life opportunities through popular prototyping?

The authors then produced an action plan according to the Theory of Change (ToC) model, wherein overall project themes and objectives were decoupled into parallel research trajectories (education, tooling and design tracks), each of which progresses sequentially through activation, training, research and development stages (Fig. 3). This action plan commences with forming the AMP makers collective, an interclass group of scrap dealers ("e-waste workers") and students and young professionals in STEAM fields. Tooling refers to development of the AMP toolset, tools and equipment to empower manipulation of 3E-materials, whereas Design in the ToC denotes broad access to design knowledge and skills, specifically as facilitated by means of the AMP digital platform, and including the ability of makers to add value and expand markets via design process.



3. Theory of Change (ToC) diagram for AMP project definition.

ToC for the AMP pilot project defines the below listed as observer-participant groups in the stellate design process:

- *Researchers:* The principal investigators of the study, co-leads of AMP and authors of this paper, who are privy to and participants in a larger research agenda that seeks to better understand Agbogbloshie, informal sector recycling activities in general, and the concomitant environmental health and safety implications of both. This group may also overlap with NGO community engaged in outreach activities of various forms within Agbogbloshie and environs.
- *Scrap dealers:* This is the predominant term commonly used to describe the constituent members of the Agbogbloshie scrapyard and recycling area, who are chiefly engaged in dismantling and disassembly activities across a spectrum of scrap types. Many if not most are equally members of the Scrap Dealers' Association, Agbogbloshie branch, an industry trade group founded in concert with Government of Ghana.
- *STEAM:* A self-selected group of students and recent graduates in Science, Technology, Engineering, Arts and Mathematics fields, both locally in Ghana and internationally, who elect to bring their technical education to bear on cooperative capacity-building in both Agbogbloshie and broader maker ecosystems.
- *Makers:* Diverse collection of individuals working not only in Agbogbloshie (e.g. computer repair and refurbishment workshops, small-scale aluminum smelters) but also situated adjacent in the Accra Timber Market (e.g. the carpentry, metalworking, tinsmithy outfits and equipment manufacturers) and distributed further afield (roadside electronics repairers, mechanics, welders, glaziers, furniture craftsmen, seamstresses and tailors city-wide) who make and repair items for a living.

(2) Explore: discover new data

In order to ascertain the underlying structure and operational mechanics of the Agbogbloshie ecosystem, representatives of AMP first conducted over several months fieldwork consisting in tandem of physical exploration of the site and personal interaction with people actively working there. Both structured and semi-structured interviews were used as a way to engage the community and enroll e-waste workers in the AMP project, in addition to baselining needs assessment. This process of circumnavigating the landscape served to gather intelligence and aggregate views and preferences across the local community.

The interviews were carried out by members of the community of scrap dealers in Agbogbloshie, trained by the AMP team, at the work sites of other scrap dealers and makers. A base questionnaire organized the interview process while allowing the interviewer to enter into a more general conversation with a given interviewee. The questionnaire covered a range of topics, including cultural/ ethnic associations (plus geographic location of origin, and language fluency); scrap/e-waste expertise (why and how initiated into the scrap trade, which types of scrap and/or e-waste processed, daily processing capacity and revenue models); training (level of formal education completed, how practical know-how/knowledge acquisition performed); health awareness (level of comprehension regarding hazards of toxic materials and processing methods, protective measures utilized); and personal aspirations (what each interviewee hoped to be able to do or accomplish in future, if anything were possible). A total of 690 interviews were carried out, representing approximately 10-20 percent of the number of scrap dealers active at Agbogbloshie per current estimates in the literature.The overwhelming majority of those interviewed identified with the Dagomba tribe from Northern Ghana, and entered into the scrap trade through their social networks of friends and family.

This fieldwork yielded two key insights that highlight the particular importance of M&D methodology and interclass innovation:

- *Made-in-Agbogbloshie:* Along-side those who concentrate on dismantling and disassembly activities, a nontrivial number of makers engage in manufacturing of tools and equipment locally within Agbogbloshie. This local manufacturing base not only makes tools (such as chisels) to assist scrap dealers in manual disassembly of scrap, and products sold city-wide, nationally and even exported to neighboring countries (e.g. recycled aluminum cooking pots, cook stoves and gas ovens fashioned out of reclaimed sheet metal), but Agbogbloshie makers also manufacture machines (such as a bicycle wheel-driven blower for aluminum smelting) that are used locally to make these tools and products. Many people outside of Agbogbloshie are unaware of the symbiotic relationship between the scrap industry, informal sector recycling and local manufacturing already in place at Agbogbloshie. At once a powerful example of on-going knowledge transfer and testament to the intertwined nature of making and recycling, this maker ecosystem constitutes precisely the local manufacturing network that AMP aims to amplify.
- *Self-learning:* Existing methods of knowledge and skills acquisition employed by the youth in Agbogbloshie demonstrate aptitude for self-guided practical education, both through hands-on trial-and-error and via oral peer-to-peer knowledge transfer. In contradistinction to students in a traditional classroom setting, these young people act independently and rapidly according to an alternative heuristic mode of learning-by-doing (linked no doubt to an underlying economic imperative). This predilection for self-learning suggests an opening for the AMP makerspace if positioned as a sort of vocational workshop or 'school of making' that leverages the knowledge already developed on the ground by youth through peer-to-peer learning and practice. Scrap dealers were responsive to the idea of access to applied forms of knowledge that could amplify their earning potential and upgrade their quality of life.

(3) Map: order data set

During fieldwork, the AMP team observed workers engaged in a range of activities at Agbogbloshie that vary from sourcing, buying, collecting, storing, trading, weighing, transporting, scavenging, dismantling, disassembly, repair, refurbishing, hacking, casting, welding, forming and making. Consequently, the mapping strategy sought to organize this data set, captured in the field as photographs, video and audio files as well as GPS tracks and waypoints, according both to geolocation and by means of tagging the data to correlate to categorized spatial activities and environmental attributes.

Tags added in post-processing encode additional information per specifications of AMP fieldwork guide: popular names of place locations within Agbogbloshie processing zone ("One Million", "Sikkens", Plastic Yard", "Onion Market", "Galloway", etc.); activity type (disassembly, repair, make, pray, rest, weigh, transport, feed, etc.); materials present at a given location, or in a given image/video/audio sample (copper, steel, aluminum, brass, plastic, etc.); equipment type (refrigerator, microwave, television, mobile phone, air conditioner, etc.); component parts (circuit board, condenser, motor, engine block, compressor, etc.); tools for processing (hammer, chisel, spanner, screwdriver, scale, etc.); **"**micro-tecture" (micro-architecture) and infrastructure.

Mapping this information is thus a process of visualizing variation in materials, objects and activities observed across the territory of Agbogbloshie where scrap is processed, so as to render visible the "informal" ecosystem of recycling extant at Agbogbloshie. This approach clarified, for example, that the ubiquitous weighing scales used to check the "weight" of scrap processed (typically a spring scale or mass balance reading in pounds or kilograms) represent one of the most essential tools in Agbogbloshie, and are highly distributed across the entire site. Additionally, the map made legible relationships between spiritual, material and social dimensions: e.g. a total of 16 community mosques populated the Agbogbloshie scrapyard site (prior to demolition exercises carried out by the Accra Metropolitan Area task force in March 2015), not only building zones of trust and community but also spatializing practices of hygiene around cycles of ablution and prayer, in opposition to toxic hazards.

(4) Co-Design: design code cooperatively

Co-design as a procedural step implies to design cooperatively, to integrate multiple constituencies into a joint design process. Code design is a form of consensus-building and making together (see 5: Prototype), through which participants generate shared design code. Design as code is not pure algorithm (visual, logical, material, etc.) but more generally parametric, anticipating not only current conditions, but also future ones. Co-design approximates genetics the more it is developed with all stakeholders in order to maximize adoption, ease of entry to user network.

While Agbogbloshie is multiply contested terrain, the geolocation of the AMP spacecraft installation (i.e. location of the makerspace relative to the Abose-Okai Road, main route into Agbogbloshie scrapyard, National Youth Authority building, Scrap Dealers' Association and Onion Market) is an output of a participatory mapping process leading to codesign. The architecture of the structure and this site location, close to the road and entry, intend to increase fluidity (ease of encounter) between social groups of scrap dealers and STEAM. However, while it may become relatively easy to initiate M&D work on projects (e.g. tool development), any such effort requires energy and resources to sustain over time.

For this reason, codesign and prototyping workshops play a central role in M&D process. Organizing and running workshops functions as a mechanism to ensure that pathways to participation remain open, i.e. that people who want to get involved with the design process and project(s) can find welcome access. Workshops are organized either as codesign workshops, i.e. joint exercises in ideation and "design thinking", typically with a primary focus of outreach, or as maker workshops, which are more hands-on and materials-based, and which form a technique of participation during prototyping. Both types of workshops, as well as blends of the two, are subject to the various time constraints of simultaneous group work, and must address the need to remind participants to think creatively.

Codesign workshops made use of several key strategies to drive participation both from within the Agbogbloshie community and that of students and recent graduates in STEAM fields, including:

a) *Sourcing materials from Agbogbloshie:* Sourcing materials was a way of exposing STEAM stakeholders to Agbogbloshie. It also afforded members of the Agbogbloshie community who may lack the time to attend an off-site workshop a window into the M&D process. For example, workshops to make Jerrytop computers (new computers built in plastic Jerry cans with upcycled components from e-waste) saw participation of several computer repair and refurbishment shops in Agbogbloshie, working together with young STEAM professionals. Some members of the e-waste and scrap community expressed keen interest in learning how to make the computers as an entrepreneurial venture.

b) *Manuals for e-waste:* Participants developed a series of manuals about the various types of electrical and electronic equipment (3E) commonly processed in Agbogbloshie. Desk research was carried out by STEAM students, but field research involved their participation on the ground in Agbogbloshie with scrap dealers. The iterative nature of the design process meant that many members of both communities had an opportunity to give feedback on each successive version, as well as to help provide additional information, such as examples of new upcycled products that can be made out of e-waste and 3E-materials. Co-design of the maker manual demanded integration of the needs and expectations of people from

different social backgrounds, each with different levels and forms of understanding and knowledge. It became apparent that e-waste and scrap workers in many cases display a default disinclination towards step-by-step instructional guides if presented on paper because the standard approach to dismantling in Agbogbloshie is based more on trial-and-error through hands-on experimentation than on a written or scripted process flow.

c) *Disassembly and remaking workshops:* Early stage workshops involved participants disassembling different types of e-waste including printers, fans, electric shavers, refrigerators, microwaves, laptops and desktop computers —in order to usability test the successive manual drafts as well as to investigate how assemblies, subassemblies, components and 3E-materials from EOL equipment could be re-utilized in making new devices or products. These workshops helped to demystify the "black boxes" of electronic gadgetry and share information about safer ways to disassemble and manipulate 3E properly. Subsequent workshops transitioned increasingly into "remaking", i.e. finding ways to recombine components sourced from within the e-waste stream to produce new types of equipment. These concept technologies were then prototyped through a series of maker workshops.

(5) Prototype: test by making

The purpose of the prototyping phase is to evaluate design concepts by and through making them. In M&D process, this is more specifically considered as popular prototyping, which on one hand signifies a commitment to involve an array of people from a designated community, who may not necessarily have a high degree of technical proficiency, and on the other hand expresses the notion that if a product or instance of technology adequately satisfies the needs of people, then they are more likely to like it.

Members of the Agbogbloshie community who specialize in e-waste dismantling, computer repair and plastics recycling all contributed significantly to the prototyping process, as did craftsmen from Accra Timber Market, a light industrial hub adjacent to Agbogbloshie, who assisted with tinsmithing, welding and metal fabrication. Students who participated in the maker workshops spanned STEAM fields from medicine, psychology, chemistry, physics, materials science and nanotechnology, aeronautical, mechanical, electrical and electronic engineering, to photojournalism, communications, architecture and urban design.

The backgrounds of participants in the maker workshops typifies the socioeconomic and cultural diversity prioritized as a driver of interclass innovation. Myriad times the results of this cross-fertilization were remarkable. A notable example was when a group of engineering students were converting fans from e-waste into windmills but with insufficient gear ratios were generating low voltages. In response, a scrap dealer from Agbogbloshie ran off into the scrapyard and returned with an old dynamo from a bicycle headlight and showed them how not only could it enable them to increase output voltage levels, but it was also bidirectional!

IV. Conclusions and Next Steps

AMP contends that—at the advent of smart cities and the Internet of Things—(domains of) architecture and electronics have converged. At such a moment—if we capitalize on this opportunity to make open, democratic and collective the capability of manipulating materials from the level of chemistry up, by means of digital technology—we can move beyond the notion of "e-waste". Electrical and electronic equipment (EEE or 3E)—old or new—constitute a vital stream of raw material for the global production chain. Not only are such 3E-materials the physical building blocks of digital space, but many are also recyclable, i.e. plastics, steel, aluminium, copper, glass or other valuable materials. If successful, AMP aims to amplify the economic potential of maker ecosystems, sustainably, starting at Agbogbloshie.

Progress to date suggests that there may indeed be nontrivial potential to drive (micro-) innovation locally within Agbogbloshie via unconventional "bottom-up" methods that link social networks across ethnic and class divides and make space for youth-led engineering design exploration. The initial findings of the AMP design research project suggest that, when granted the opportunity, youth from a wide range of backgrounds in Accra, Ghana may choose to participate in codesign of a local innovation ecosystem.

However, a number of challenges remain. On a basic level, there is need to introduce additional competency in design into the target youth populations. Given that many participants have had limited experience making and building things, there is a learning curve with respect to gaining familiarity with the iterative nature of design. That is to say, some participants were inclined to rush through the process of assembling components in order to "make something", without fully recognizing the importance of incremental fabrication and testing. Furthermore, there is an inherent tendency of some items produced in the wider context of the informal sector to read as haphazardly constructed and potentially liable to exhibit poor performance. This can only be overcome through improved techniques of design and engineering.

If, broadly speaking, the purpose of AMP is to build an innovation engine—i.e. to motorize the informal mechanics that currently energize Agbogbloshie as a dynamic T.A.Z., revolving around recycling and small-scale manufacturing—then like any motor or engine it requires fuel or a constant power supply. Further development of the Agbogbloshie Makerspace Platform is thus integrally tied to advancing a model that guarantees that the requisite inputs (resources) are both available and consistently applied over time. One approach is to create an economic model, closely calibrated to the existing ecosystem at Agbogbloshie, that provides locally-relevant jobs as well as revenue that can be reinvested in both the platform infrastructure and further M&D cycles.

The next step of this design investigation extends to the codesign and user testing of the AMP digital platform (qampnet), which seeks to operate as an interactive tool for information-sharing. This process draws on the data collected through the stellate design process thus far, but broadcasts it as a peer-to-peer mobile phone-based network for collaborative making. As it turns out, making better use of the 3E-materials present in the e-waste stream at Agbogbloshie begins with building trust between people.

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