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Design of a Comprehensive System to Benchmark Makerspaces

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Abstract

Makerspace, a term coined in the early 2000s by MAKE Magazine, is an umbrella term for many organizations that share a common goal; to support creative self-efficacy. Makerspaces can be understood as the 21st-century evolution of libraries - communities allowing members with shared interests to collaborate on developing ideas while socializing the financial burden of equipment access and upkeep. A makerspace can look very different from place to place, with some being located in public spaces like libraries or classrooms. Others can be privately owned facilities, either open to the community or for-profit enterprises charging access fees. Assessing and benchmarking these spaces' capacity and capability can be difficult due to their wide variety of attributes. There is rapid worldwide growth and evolution of makerspaces that frequently outpaces research efforts resulting in a lack of comprehensive analysis.

Creating a comprehensive framework for assessment will enable makerspaces to utilize a common language for comparison on like terms, allowing for more streamlined collaborative research to assess capability, safety, social impact, and economic contribution. A thorough literature review was conducted on makerspaces. Numerous attributes of makerspaces and maker communities were then sorted into broader dimensions. These dimensions include physical assets, culture, influence, and sustainability of a makerspace. The authors propose numerous indicators that could be utilized to quantify these makerspace dimensions. This assessment framework will enable future researchers to look at holistic data and influencing factors, encouraging more structured investigations on the many impacts of makerspaces on their members and community. Makerspaces are an unrivaled tool in hands-on experiential learning, and by creating a common framework, research on educational impacts can be shared among previously disparate efforts.

1. Introduction & Motivation

As makerspaces become an increasingly influential part of the development of products and ideas, the need for a standardized classification system becomes increasingly apparent. Makerspaces are "workshops organized with an open community model where people with technological interests can come together to socialize, collaborate, share and expand their knowledge" [1]. This definition is explicitly broad to allow for the many types of spaces under this umbrella term. Today, makerspaces exist in various forms to serve different stakeholders and for other primary objectives. Within the ASEE PEER database, over 370 articles related to the term "makerspaces" have been published since 2015.

With an ever-growing body of research, there is a need to develop a common framework to define the various characteristics of makerspaces. Both researchers and readers can effectively determine the reproducibility and merits of the research insights applicable to one type of makerspace to another. In a recent publication [2], the author noted that makerspaces differ in setting, materials, components, and equipment. There are differences in the stakeholders - users and managers and the mission/objectives of the space. Benchmarking is an essential tool for the continuous improvement of quality [3]. As R.M. Epper noted in [4], benchmarking is a systematic way of learning from others and changing what you do. This paper seeks to clarify and combine existing research on taxonomies to aid with the classification and benchmarking of makerspaces. Prior taxonomies were combined to broaden their scope outside of their specific research. The paper's overarching objective is to help makerspaces develop a common vocabulary to articulate their modus operandi, their impact, and their growth to help other spaces identify, realize, and internalize more recent reported best practices. Makerspaces can utilize the framework established in this paper to document their current status and use internal benchmarking processes to track their growth and impact. The classification framework developed in the paper could be utilized to clearly identify the commonalities and differences between makerspaces by feeding information on the attributes of the different makerspaces into a comparative model such as a C4.5 decision tree [5]. This paper's fundamental merit is to leverage scholarly work from various fields of business, science, and mathematics to craft a holistic classification system for makerspaces - that span across the contexts of formal/informal education and corporate makerspaces.

2. Defining Makerspaces

Defining a makerspace is a difficult question. While most makerspaces label themselves as such, the boundaries begin to blur when overlapping terms apply, particularly with spaces that serve multiple purposes. The terms "hackerspace", "hacklab "fablab", "TechShop", and "makerspace" are often used interchangeably for spaces sharing a similar genealogy. As noted by Voight et al. [6], clear terminology is usually a sign of an established research area. It is evidence of a sufficiently large body of knowledge describing the boundaries of a term and interdependencies between terms.

Hacklabs are one of the earliest incarnations, first appearing in the late 1990s [1]. These spaces were traditionally focused around an anti-authoritarian ideology, often containing equipment for circumventing copyright and other illegal activities. On the other hand, hackerspaces were focused more on interaction and collaboration with a community of like-minded "hackers." As technology evolved and became more accessible, the maker movement expanded beyond dedicated enthusiasts to a broader audience.

The word "makerspace" was coined in 2005, with the publishing of MAKE magazine. [7]. MAKE was selected over HACK due to the connotations of the term, particularly in its exclusion of craftsman and artistic elements [8]. A 2020 analysis of co-words provides continual support for this hypothesis. The name is neither controlled nor regulated by MAKE, unlike many other categories.

"FabLab" had its origin in the MIT Center for Bits and Atoms, as a project to introduce fabrication tools to students and wider communities [9]. The Fab Foundation, founded in 2009 as a nonprofit, [10] now maintains a user-submitted directory of "FabLabs" [11]. The term makerspace is used as a generic signifier, with FabLab used as a specific member organization. Similar to FabLab, TechShop was a for-profit enterprise started in 2006 intended to provide access to makerspace equipment to any member of the public paying their membership fees [8]. TechShop filed for bankruptcy in 2017, closing all US locations, although other TechShops remained operational internationally. Other terms have less clear origins and definitions. Innovation Labs and Coworking spaces are typically defined by their goal of achieving set goals, such as research or commercial products [1]. However, any space can brand itself as a coworking space. Despite the movement's roots in European hackerspaces, coworking rental companies such as WeWork are far from the contemporary roots of makerspaces [12]. As Rieken et al. [13] have reported, even companies have started to invest in building corporate makerspaces in order to leverage their role as drivers of innovation.

Research in 2015 was done to explore the links between these terms, specifically using Twitter to infer communities based on follower connections. Hackerspaces occupied roughly a third of the network, with makerspaces half of that. FabLabs typically existed within a peer network, often based on language [14]. The key commonality all these terms have is the community-based model, the concept of sharing space to collaborate and create. While these elements' execution may vary, taxonomizing them in a standard structure is an achievable endeavor. For the scope of this paper, the definition of makerspace is assumed to be broad and encompassing in nature, i.e. all forms of spaces that enable people with common technological interests to come together to socialize, collaborate, share and expand their knowledge.

3. Prior work on taxonomies and benchmarking

Makerspace quantification is not a new method of inquiry; a number of systems have already been developed to facilitate makerspace research. These systems frequently focus on one specific category or method, such as higher education makerspaces [15]. This research aims to build on these prior taxonomies to aid in the consolidation of research into a more accessible standard. "The long-term goal is to start with a draft, which is progressively unified and becomes an increasingly accepted terminology that precedes comparable and eventually generalizable knowledge" [6]. As such, the proposed system incorporates many elements of previous categorizations while creating room for the classification of novel spaces. The primary research this exploration was based on is listed below. Some categories were summarized or paraphrased from the original papers for brevity and clarity. Many papers also included basic information such as age, size, or address.

"State of the Art of Makerspaces - Success Criteria When Designing Makerspaces for Norwegian Industrial Companies." [16] was an analysis that used true/false questions to assess how widespread a category element was. For example, for the "Tool dominance" section, 11 out of 13 surveyed makerspaces had a 3D printer, but only 5 out of 13 spaces had a foundry. Key takeaways from this paper include its discussion on User Literacy and user stories, which provided valuable insight into the various ways makerspaces engage their community and their users. "A successful makerspace is a used yet tidy makerspace" was a core representation between the elements that have to be balanced for success, which was the key focus of the paper. While makerspace classification doesn't quantify success, knowing which categories are useful in a makerspace's effectiveness is valuable in application.

Analysis and Comparison of Representative Locations in the General Makerspace Panorama [17] was a broad analysis that looks at the maker movement, classifying makers as people, classifying makerspaces, and measuring the effect of makerspaces on users. This also used a percentage system, rating makerspaces on whether they possessed certain qualities, such as the type of tools, classes, education, access, and funding available.

A Classification System for Higher Education Makerspaces [15] used a tiered ranking system that assigns letters and numbers to a space to create a formalized ranking. Only spaces in higher education are considered in this proposal. The categories were more limited, focusing on just scope, Accessibility, user count, footprint, and management. The ranking presented by this system implies a hierarchy, something infrequently emphasized in other research.

Quantitative Survey and Analysis of Five Maker Spaces at Large, Research Oriented Universities [18] was another similar comparison but focused on including international elements of various universities. Many categories were assessed using hours per week, such as community hours, supervised hours, and special access hours. It also included focus and plans to expand, a unique look at a makerspace's growth.

Compared to existing literature, the goal of the proposed novel taxonomy is not to be used as a direct, objective ranking system. However, the proposed dimensions and categories would lead to the creation of a well-defined vocabulary to help identify the commonality and differences across various makerspaces. For example, research focusing on a makerspaces' contributions in the development of leadership qualities, aspects of the culture category would likely be weighted higher than others. A different research effort, such as the impact on local entrepreneurship, may focus more on assets and economic factors over cultural and internal quantifiers.

4. Approach to develop a classification system for Makerspaces

A bottom-up approach was utilized in creating a classification system for makerspaces. The first step was to identify the various attributes or characteristics of a makerspace as reported in contemporary literature. These various disparate discrete attributes were then clustered together under primary thematic areas based on affinity between the characteristics. Later, a top-down approach was utilized by further exploring the thematic pillars to identify the various qualitative and quantitative indicators that could be used to define them for benchmarking purposes.

4.1 Makerspace Attributes

Parsons et al. [19] noted that the classes used in a classification system should be formed on fundamental cognitive principles. One of these principles states that classes should be designed such that they incorporate inferences about the properties of their attributes. Hence, before developing classes for makerspaces, the first step was to explore and list every documented attribute of makerspaces.

The most common attributes of makerspaces found in the literature were the space's physical environment and the tools/equipment available in the space. Tools are only useful in a space they can function safely and adequately. Space (or workspace) focuses on the size and functionality of the makerspace as a location. Square footage is a useful starting metric [15], but considerations of fixtures and other internal elements are important. Many types of common makerspace machinery require a higher voltage outlet, as well as pressurized air and ventilation [20]. Hence, it is important to consider the capability of the space for expansion when trying to understand the space of the makerspace itself.

Secondly, another important attribute of the makerspace is the types and number of tools available. The quality and caliber of tools is often a ceiling on the quality of items that can be produced by a given space. While this may seem a basic assessment, in one survey, only 60% of makerspaces include physical hand tools, while 73% include digital fabrication tools such as 3D printers [17]. Availability of a tool often follows the mission or objectives of a makerspace. Benchmarking the functional fidelity of a makerspace isn't a novel method of inquiry but is difficult to accomplish comprehensively. Adam Kemp, in "The Makerspace Workbench", [20] proposes the tech levels of low, medium, and high for a given task, such as making a hole in a metal plate. The low-tech solution is a hand drill with a hole saw, and the high-tech solution is a CNC mill. Depending on the end goal of the proposed comparison, tools can be stratified further into fidelity levels.

Financial support is essential to the success of a makerspace. While many makerspaces are grassroots efforts, grants, donations, and membership fees are all important to keep the lights on and influence development. It is important to consider the operating budget and details such as the funding source and restriction to specific goals a makerspace may have. A makerspace in higher education may be required to spend funding to accomplish a specific university mission [15], restricting its ability to use funds in a discretionary way.

The way a makerspace provides funding can impact its relationship to its members, as many spaces directly tie access to membership fees [16]. Examining the structure of a makerspace is often done from the lens of administration styles. Higher education makerspaces, for example, have been classified over whether staff or students manage it [15]. Other spaces are classified by what paid roles exist, as opposed to volunteers. [16]. It can be difficult to compare spaces by this aspect, as while a higher education makerspace may have no explicit entry fee, their funding can come from tuition or additional fees for students. [21]. This concern is also somewhat addressed by the Access provision in Wilczynski's [15] paper, but the highest threshold remains at "entire University community". Jensen et al. [16] compare the target audience of spaces, but categories such as "Children", "Makers", and "Entrepreneurs" are loosely defined as to who falls into those buckets. Manas Pont [17] has the most explicit ranking of openness, ranging from access restricted to students only to open and free access to anyone, alongside a target user category.

Makerspaces do not exist in a void - they also affect their nearby communities. Some spaces make it their mission to influence or improve their community, while others intend just to serve their membership. This online article on a dataset of UK Makerspaces [22] proposed an initial method in 2015 of ranking a makerspace leaning on a scale of inward vs. outward, and Manas Pont [17] ranked a number of makerspaces on this scale, using aspects such as access, workshops, proximity, and entry fee requirements. Proximity, in this case, refers to the surroundings of the space, such as TechShop Detroit's location near Ford automotive campuses. Woolls T. [23] identifies four different ways makerspaces can influence their members and community: financial support, technical support (Training Events), social support (Location, Virtual events, and Presence on Social Media), and diversity support (Training events engagement with the community).

The impact of a makerspace can also be assessed from deliberate outreach efforts, such as social media presence. Exciting research in the field of social media impact was focused on mapping changing meanings of makerspace terms, making research repeatable, and generalizing knowledge in the space. The methodology employed was to "combine data-driven analysis with conceptualizations based on a deep understanding of the domain where the taxonomy is to be used" [6]. The researchers performed a similar analysis to that of [14], but instead of focusing on peer relations, used keywords in a number of maker-adjacent communities. Here, growth and overlap of terms can be observed from the perspective of those outside of the network. The seed categories the research focused on were people, places, and activities. The analysis presented three distinct clusters, "(1) kids learning in maker spaces, (2) supporting students in maker spaces, (3) schools and libraries as maker spaces". The paper highlighted how social media can be utilized as a tool to develop a vocabulary for classifying activities within a makerspace. Numerous researchers [25-27] have also conducted empirical/qualitative studies that provide an additional basis to define more makerspace attributes. Table 1 lists the various documented attributes of makerspaces from literature.

Table 1: Examples of makerspace attributes as documented in various literature

Attributes / Characteristics	**Meaning**	**Type**	**References**
Tools/Equipment	Capabilities of machine tools	Qualitative	[15], [16]
Workspace	Size in Sqft	Quantifiable	[15]
Funding	Funding sources	Quantifiable	[16]
Membership	Average skill level of member	Qualitative	[24]
Administration	Number and structure of staff	Quantifiable	[18]
Location	Proximity to outside partnerships	Qualitative	[17]
Presence	Average engagements per week on social media	Quantifiable	[6].
Outreach	Workshops provided yearly	Quantifiable	[17]
Motivation of users	How did users interest and achievement emotions about the makerspace change	Qualitative	[25]
People	Individual experience and how individuals interact	Qualitative	[26]
Teaching methods	How instructors teaching methods effect the work in a makerspace	Qualitative	[27]

4.2. Grouping Makerspace Attributes

One approach for solidifying makerspace characteristics into accountable metrics is presented in [16], which suggests separating categories into qualitative and quantifiable aspects. In reference to Table 1, workspace and tools are both closely linked, as space itself can impose a limit on the tools it can house. Certain aspects, such as funding, can include multiple approaches, such as looking at the overall revenue for space (quantitative) while also considering the restrictions on usage that funding may have (qualitative). For example, makerspace funded through State funds or Govt. sources cannot be utilized to benefit a specific for-profit private company or organization directly. Hence, the ability of tangible assets to impact a specific community also depends on elements that govern the continuity of the space.

When looking at a makerspace without its physical assets, all that remains are the people making the space function. Access is always a huge element of a makerspace, as what audience the space is serving affects its character and growth. Membership and administration are often closer than in similar organizations, and both are important elements for a space's future. As noted by Davies et al.,[28], various stakeholders play different roles in a makerspace, and their attitudes can help define the culture of the space. Several makerspaces do include complex high power equipment with the potential to cause physical harm. Therefore, an assessment of safety procedures, incidents, and overall attitude towards safety is a valuable indicator of the culture of the space.

A makerspace's plan for continuity is a crucial characteristic to be considered when benchmarking makerspaces. Looking into the methodology of education of new members and ability to pass on institutional knowledge, "operational gaps" was proposed by Spencer et al. [24] as a time in which tooling and procedural information was lost due to departure of its key early members. This could easily invalidate a prior assessment of a space, as its capabilities may change drastically according to specific members' arrival or departure. Hence, a category to essentially assess volatility can be extrapolated from the continuance plan for the makerspace. It is also important to look at maintenance plans for the physical assets for the space. A makerspace with a lot of funding, for example, may use outside repair people for tools, but for other spaces tools must be fixed by members lest they fall into disuse. Continuance plans for members and tool maintenance themselves do not entirely address the Sustainability of a space. The existence of a vision or a long-term plan can influence both the space's physical assets and culture.

A makerspace exists to have a specific impact on the community it serves. Many researchers have tried to develop various assessment tools to measure the impact of a makerspace. A makerspace's ability and willingness to do outreach with workshops and attending maker fairs are a way to gauge the community's overall sentiment. Makerspaces are also considered very "online", as much of the DIY movement was spawned from the interconnectivity of the internet [7]. The willingness to interact with the wider internet community and the sentiment of those interactions can also help with determining the general perception of the space. A space's proximity to a community through online activity can also affect every aspect of its character. A high-level summary of the proposed system with example indicators is shown in table 2. Makerspaces can then be explained as places that contain ***Physical Assets*** to support a ***Culture, which*** ensures its ***Sustainability*** to yield an ***Influence*** on a community. The terms can be defined as follows:

- **Physical Assets**: A tangible resource of economic value that is controlled by the stakeholders of the makerspace.
- **Culture**: The characteristics and knowledge of the stakeholders of the makerspace which encompasses their social behavior.
- **Sustainability**: The ability to maintain or grow/expand the makerspace
- **Influence**: The ability to have an effect on the character, development or behavior of the makerspace stakeholders.

Table 2: High-Level Summary of the proposed classification system

	Physical Assets	**Culture**	**Sustainability**	**Influence**
Qualitative		Mission & Values	Education Tools	Proximity to communities
		Stakeholders	Maintenance Protocols/Plans	Engagement with various stakeholders
		Access rules	Vision	
		Training protocols and Safety Controls		Engagement with Community
Quantitative	Machines/Tools	Ratio of new to returning users	Revenue Streams (amount and source)	Presence on Social Media
	Workspace	History of the organization	Conversion rate of users into staff	# of training events and workshops
	Availability/Accessibility of raw materials		Service history of staff members	# of users

5. Definition of Proposed Makerspace Classification Categories

Based on the above classification system, a complete framework for classifying makerspaces based on the four major classification elements is proposed, along with a variety of attributes that can be sorted into the four elements. Possible methods for tracking these attributes within a makerspace are also suggested.

5.1 Physical Assets

When attempting to classify a makerspace, one of the largest and most influential factors is the space's physical assets. Regardless of other attributes such as user competency, funding, or leadership structure, a space's physical assets are both concretely quantifiable and can help to estimate a space's potential to accomplish its mission. Physical assets can also help gauge whether or not that potential is being fully utilized.

The makerspace's physical footprint can indicate the basic storage potential of the space. Moreover, further qualification of the space in terms of the existence of fixtures such as electricity inputs, plumbing, and ventilation can provide information regarding the space's Accessibility, safety, and efficiency.

The largest subsection of physical assets lies within the proficiency of machines and tools. Machines in space can be classified by their capabilities in operational physics (e.g. additive or subtractive) and any unique individual attributes spanning age, energy consumption, and consumables needed to power the machine. Furthermore, a tool/machine's complexity can also be used to classify it. Complexity can be divided further into the ease of repair/maintenance and the ease of use, which consists of the training, knowledge, and time investment necessary to use the machine and train a user. Lastly, the physical capabilities of a tool or machine should also be noted in classification. For example, the type and maximum/minimum size of raw material accepted by a machine, as well as the tightest tolerances achievable, should be noted.

The last subsection of physical assets is the availability and Accessibility of raw materials. Members of a makerspace need access to raw materials before they can use the makerspace. The availability of different raw materials can have an impact on what people do in the makerspace. For example, academic makerspaces often provide raw materials for 3D printing for students, which makes 3D printing a very accessible method for students to make things.

Much of the data needed to classify a makerspace based on machines and tools, such as individual attributes, operation physics, capabilities, will need to be obtained manually from the machine/tools manual or other documentation. Likewise, workspace attributes like available fixtures will have to be manually recorded. Following are some of the key indicators to assess the physical assets of a makerspace:

- **Workspace**
    - Footprint (sqft)
    - Fixtures
        - Plumbing
        - ADA Accessibility
        - Ventilation
        - Climate Control
        - Electricity/ power
- **Machines/Tools**
    - Complexity
        - Ease of repair/maintenance
            - Ease of detection of a fault
            - User serviceable parts
            - Frequency of downtime
            - Open Source
        - Ease of use
            - Operator Requirements
                - Time investment necessary to go from trainee to a user

                - Prior knowledge necessary before training or using
                - Training Threshold to prevent common injury
            - Cognitive load on the user while operating the machine
            - Trainer Requirements
                - Time investment necessary to move from being operator to trainer
                - Training needed beyond operator requirements
    - Individual Attributes
        - Consumables needed
        - Footprint
        - Cost
            - Acquisition cost
            - Installation Cost
            - Operational Cost
        - Energy Consumption
        - Age
    - Operation Physics
        - Additive
            - Material Deposition
            - Energy Deposition
        - Subtractive
            - Mechanical Abrasion/Shear
            - Thermal Abrasion
    - Capability
        - Max. range/size
        - Raw material type
            - Polymer
            - Metal
            - Ceramic
        - Possible Features
        - Tolerances achievable
- **Availability/Accessibility of Raw materials**
    - Types of raw materials available
    - Proximity to materials
    - The cost incurred on the user

5.2 Culture

Culture is the most subjective element of a makerspace. Understanding the culture of a makerspace can determine why a particular makerspace exists or what kind of people visit it. Metrics for culture include objectives of the makerspace, access rule, information regarding stakeholders, organizational structure, and the age of the makerspace. Information regarding stakeholders can give insight into the makerspace's intended purpose. For example, if the controlling agent of the makerspace is a High School, the purpose of the space could be to train and educate students within the school. Conversely, a variety of different tool owners all working in a shared space may indicate that the makerspace's primary purpose is to fulfill members' individual project needs. The percent of new users that return to the space can provide insight into who is visiting the space. A high return rate may provide evidence of "professionals" or inventors frequenting the space, while lower and less frequent return rates could imply hobbyists or one-off users.

A potential data stream for collecting information on the percent of users who return requires users to sign in to the makerspace and even individual machines/workstations. In addition to tracking the frequency members use the makerspace, this can give insight into what a particular member is doing at the makerspace, which can help determine the incentives/objectives of the members. Following are some of the key indicators to assess the culture of a makerspace:

- **Incentives / Objectives / Mission**
    - For creativity and innovation
    - For effectiveness against a prescribed goal
    - Freelance/tinkering
    - For Entrepreneurship
- **Stakeholders**
    - Beneficiaries (those who benefit from the makerspace)
        - User Demographics
        - User Motivation
    - Controlling agents (influencers to the makerspace)
        - Authority or controller of activities and/or mission
        - Owner of equipment
        - Owner of space
        - Controller of Utilities/Energy
        - Controller of funds
        - Controller of materials
- **Access Rules**
- **Training and Safety controls**
    - Culture of safety and collaboration
- **Percent of new users visiting the space again**
- **History or age of the organization**

5.3 Sustainability

Another classification element is Sustainability. Metrics for Sustainability can be used to gauge the potential longevity of a makerspace. Required maintenance and upkeep of both tools and the overall space can give insight to the makerspace's ability to remain operational. The retention rate of new members and the ability to transfer knowledge to new members are key metrics to a makerspace's sustainability.

Much of the attributes used to gauge the Sustainability of a makerspace are qualitative, such as educational tools, maintenance protocols, and vision, and require a manual review for classification. However, attributes such as revenue and conversion rate of users into staff can be quantified and recorded. It may not always be possible to identity the sources of revenue or funding streams. Instead, looking at physical assets like tools could be used as a way to estimate past funding. This approach may not always work as some equipment might be a result of a one-time philanthropic donation and might not provide any insights into the revenue streams of a makerspace – which is necessary to define the sustainability of the makerspace. Following are some of the key indicators to assess the sustainability/continuance of a makerspace:

- **Educational Tools (to support knowledge transfer)**
  - Documentation standards
    - Troubleshooting guides
  - The process to recruit incoming staff
- **Maintenance Protocols/plans (for Physical Assets)**
  - Overall space maintenance/upkeep
  - Machine/Tool maintenance
- **Vision**
  - Long term and short term plans for growth
- **Revenue streams**
  - Quantity
  - Source
  - Frequency
- **People**
  - The conversion rate of users into staff
  - Service history of staff members

5.4 Influence

The influence of a makerspace can be understood as the space's impact on its community. This becomes an essential factor in space's growth and community engagement, which can help sustain the space, obtain funding, and overall popularization.

One attribute for a makerspace's influence is training and other events, both in-person and virtual, alongside wider community engagement. This can include partnerships and affiliations with local maker fairs and businesses and/or the facilitation of service projects to help the community. The space's physical location, including its proximity to public transit and zoning or other external regulations can also affect how well a space is able to reach its community. In the modern age, any establishment's social media presence has become a key factor in terms of community outreach and engagement. Makerspaces can track how well they are leveraging social media related advertising and promotions through the frequency of posts, the number of platforms on which posts are being made, and how social media engagement analytics are changing over time. Tracking attendance at training and virtual events can also give insight to the influence of a makerspace. Following are some of the key indicators to assess the influence of a makerspace on various communities:

- **Presence on Social Media**
  - Platforms engaged with
  - Engagement with others
  - Frequency of posts
- **Training Events**
  - Number of on-site events and participants
  - Event skill threshold (welding vs intro to woodworking)
  - Attendance requirements (fee, membership)
  - Cyclical vs single event
- **Virtual events**
- **Engagement with Community**
  - Number of new and returning users on daily, weekly or monthly basis
  - Influence with local celebrity
  - Reputation of members
  - Service projects
  - Affiliation with local events and maker fairs
  - Partnerships with affiliated local businesses
- **Location**
  - External regulation of space (school v/s warehouse)
  - Public or private space
  - Zoning of area
  - Proximity to public transit

6. Conclusion and Future Work

Numerous literature sources on makerspaces report on variety of attributes and best practices. The various qualitative and quantitative makerspace attributes were grouped together to identify the four core elements of makerspaces were identified from literature that could be used to categorize and classify makerspaces, namely Physical Assets, Culture, Sustainability and Influence. Possible methods for collecting indicators or metrics from a makerspace on those attributes were also proposed. The proposed framework should be a strong starting point that would allow a more direct comparison between makerspaces and help administrators and practitioners to determine if reported best practices from literature might be applicable for a specific makerspace of interest.

There is still much research to be done in the field of makerspace benchmarking and comparison. In particular, emphasis on makerspaces in English-speaking countries and their observable elements limits the scope of the proposed system, whereas cultural terms and conventions in other cultures would be valuable addition. There is also significant room for clarification within each taxonomy category and its ability to compare similar but not identical spaces. Additionally, the usefulness of this taxonomy will need to be evaluated. Szopinski [29] describes how case studies or field experiments with representatives of the makerspace community can be used to assess taxonomies. Future work should also include creating sample data sets using the proposed attributes and feeding them through a comparative model. Recent publications [30-32] present various methods by which makerspaces already collect data about users and usage of their respective spaces regularly. Leveraging these data streams along with surveys from stakeholders would be beneficial to develop case studies. These studies could help validate and enhance the proposed system by underscoring which specific attributes are vital in comparing makerspaces when measuring against the desired outcome. Defining additional parameters and usages for side-channel data will expand future researchers' toolkit to generate comparisons.

Makerspaces are and will continue to be challenging to define, and as such, the process of taxonomizing them will have to adapt and evolve. In looking at the history of makerspaces and the existing research on taxonomy, common elements present a solution for the everlasting problem of comparison. By constructing a broad yet focused system, the hope is to allow this framework to simplify collaboration across disparate research attempts.

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