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Systematic Review and Classification of the Engineering for Global Development Literature Based on Design Tools and Methods for Social Impact Consideration

While many tools and methodologies for assessing social impact exist and are used in the social science and global development fields, there is a lack of standard methods for considering the broader social impact of products in the engineering community. Some reasons these methods are not as widely used in the engineering community include designers not being aware of the methods, or methods not being widely applicable. The purpose of this research is to help designers and researchers find relevant design tools and methods for implementing social impact considerations. This is done through the classification of 374 papers in the Engineering for Global Development (EGD) literature along several dimensions including method purpose, industry sector, social impacts considered, sustainable development goals, paper setting, and data inputs required. This article describes how designers and researchers can use this set of classified papers to locate relevant design tools and methods to improve social impact considerations in their work.
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Keywords: social impact, engineering for global development, humanitarian engineering, design theory & methodology, systematic review, meta-analysis, economic & social effects, social aspects, sustainable development, product development, product design, framework, process, method, tool, assessment, social impact assessment, modeling, qualitative and quantitative data, sustainable development goals, cyber physical social systems, design for humans, user-centered design

1 Introduction

Every product has economic, environmental, and social impacts despite whether these impacts are explicitly considered [1]. These impacts affect society and are an important part of engineering design. “Triple Bottom Line Sustainability” focuses on economic, environmental, and social sustainability and has become an important goal for those designing products [2]. Economic considerations are an established part of the engineering design process [3]. Environmental considerations are increasingly being considered in design including the development of design standards and widely used methodologies [4,5]. Social impact considerations, however, lack the standardization and wide inclusion of economic and environmental considerations [6,7]. This results in reduced and unbalanced consideration of social impacts compared to economic and environmental impacts [8]. Improved consideration of social impacts in engineered products would benefit society in many areas of life [9].

While many tools and methodologies for assessing social impact exist and are used in the social science and global development fields, these tools are not widely used in the engineering community [10]. Some reasons these methods are not more standardly practiced include designers not being aware of the methods, methods not being widely applicable or adaptable, methods being too complicated or time intensive to use, or methods not being useful in product development processes [10,11].

One reason it is difficult for researchers and practitioners to be aware of social impact tools and considerations is due to the diverse nature of fields tackling these problems, such as the Engineering for Global Development (EGD) community. These issues make it difficult for designers and researchers to locate what they are looking for. For example, a review on the state of EGD found that the field is often described by nine different names such as “social design”, “peace engineering”, “humanitarian engineering,” and os on [12]. To further illustrate this challenge, consider the meta data presented in Figs. 1–3, which summarizes the 374 EGD papers discussed later in the present article. An analysis of the keywords and abstracts in this data set also shows a lack of commonly used terms, with no keyword being used in more than 11 out of 374 papers (see Fig. 1). This may be due to journals only allowing authors to select a few keywords from a set. This may provide improved searchability within a journal, but could potentially make searchability across multiple journals more difficult. Text analysis of paper abstracts shows only two phrases with a count greater than 30 times, which is low considering abstracts may repeat a phrase multiple times within a paper (see Fig. 2). Those who are not aware of the many terms used might miss substantial portions of the field due to unawareness. Figure 2 also shows a difference between the frequency of phrases occurring in keywords versus

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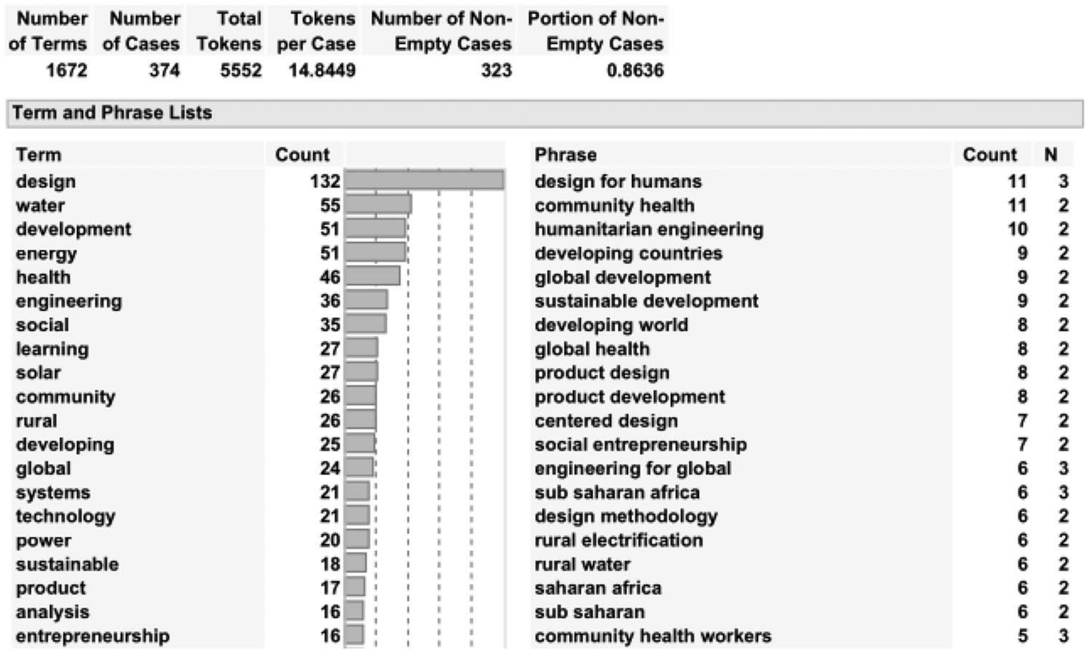


Number of Terms	Number of Cases	Total Tokens	Tokens per Case	Number of Non-Empty Cases	Portion of Non-Empty Cases
1672	374	5552	14.8449	323	0.8636

Term and Phrase Lists

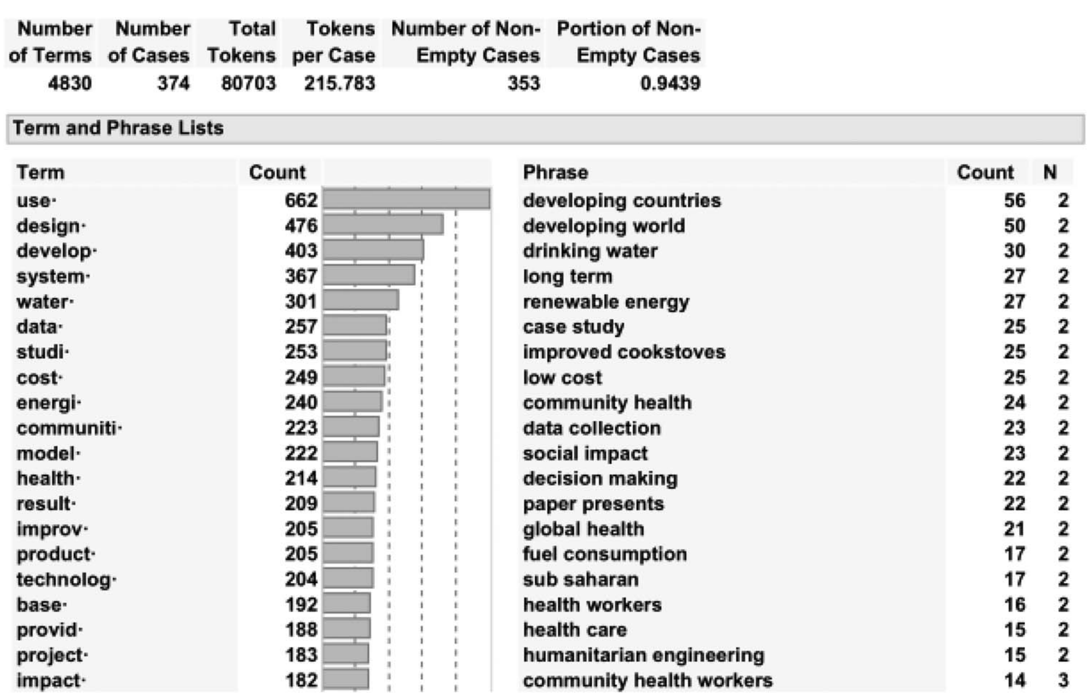
Term	Count	Phrase	Count	N
design	132	design for humans	11	3
water	55	community health	11	2
development	51	humanitarian engineering	10	2
energy	51	developing countries	9	2
health	46	global development	9	2
engineering	36	sustainable development	9	2
social	35	developing world	8	2
learning	27	global health	8	2
solar	27	product design	8	2
community	26	product development	8	2
rural	26	centered design	7	2
developing	25	social entrepreneurship	7	2
global	24	engineering for global	6	3
systems	21	sub saharan africa	6	3
technology	21	design methodology	6	2
power	20	rural electrification	6	2
sustainable	18	rural water	6	2
product	17	saharan africa	6	2
analysis	16	sub saharan	6	2
entrepreneurship	16	community health workers	5	3

Fig. 1 Keyword analysis of the paper set (first 20 lines)

those occurring in the abstracts of papers. For example, words with the stems "use" (662), "system" (367), and "impact" (182) are the 1st, 4th, and 19th most used phrases in abstracts, respectively, but do not show up in the 20 most used keywords. This suggests that keywords may not proportionally represent certain aspects of papers in the literature such as information about systems or impacts.

As will be shown, an additional problem is that there is no "one-stop-shop" for EGD literature. There is a very wide range of journals that publish EGD related work (see Table 1). The EGD paper set discussed in the present paper originates from 138 journals. This paper aims to help designers and reviewers find the information they need by organizing the literature into a large, centralized paper set organized by a common set of definitions.

Another reason that designers and researchers may not be aware of some methods is the limited level of cross organizational collaboration. Many EGD research entities develop their own methods, processes, and procedures, and there is little cross-entity collaboration or creation of general methods [11,13]. Although researchers may draw on methods from other disciplines, when a method is developed within the EGD community, it is seldom reused by other researchers. While researchers publish and present their research, these publications typically focus more on documenting the results of the methods described and less on educating readers



Number of Terms	Number of Cases	Total Tokens	Tokens per Case	Number of Non-Empty Cases	Portion of Non-Empty Cases
4830	374	80703	215.783	353	0.9439

Term and Phrase Lists

Term	Count	Phrase	Count	N
use·	662	developing countries	56	2
design·	476	developing world	50	2
develop·	403	drinking water	30	2
system·	367	long term	27	2
water·	301	renewable energy	27	2
data·	257	case study	25	2
studi·	253	improved cookstoves	25	2
cost·	249	low cost	25	2
energi·	240	community health	24	2
communiti·	223	data collection	23	2
model·	222	social impact	23	2
health·	214	decision making	22	2
result·	209	paper presents	22	2
improv·	205	global health	21	2
product·	205	fuel consumption	17	2
technolog·	204	sub saharan	17	2
base·	192	health workers	16	2
provid·	188	health care	15	2
project·	183	humanitarian engineering	15	2
impact·	182	community health workers	14	3

Fig. 2 Abstract analysis of the paper set (first 20 lines)

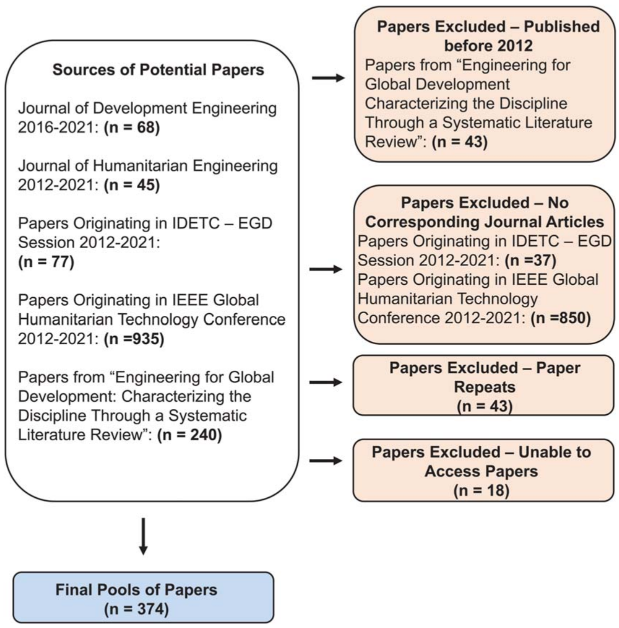


Fig. 3 Diagram of paper selection for literature review

on how to use the methods [11]. Work is being done to align the learning objectives of EGD programs in universities to better teach design tools and methods for social impact considerations [14]. In the meantime, collecting a curated list of the design tools and methods in EGD helps solve issues of low awareness.

In the field of EGD, standards for products such as water drinking products [15], improved cookstoves [16], and emergency shelters [17] have improved the testing, design, and performance of these products. Calls have been made for greater standardization throughout the field of EGD [18]. The access to the current best practices and state-of-the-art research advances the field and helps standardize practices, which is another benefit of a compiled, categorized set of papers.

The purpose of this research is to help designers and researchers find relevant design tools and methods for implementing social impact considerations by pointing them to a classified, filtered set of papers. This is done through the classification of 374 papers in the EGD literature along several dimensions including method purpose, industry sector, social impacts considered, sustainable development goals (SDGs), paper setting, and data inputs required. Section 2 describes the methodology for classifying the literature. Section 3 describes the paper attributes that were used in the classification and how those attributes may be used to help designers and researchers find and use relevant design tools and methods. Section 4 describes a summary of the results, and Sec. 5 provides a discussion of the results and general observations and insights resulting from the systematic review. The full set of classified papers is available[2].

Table 1 Papers by journal of publication

Journal name	N
Development Engineering	68
Humanitarian Engineering	45
Journal of Mechanical Design	17
Energy for Sustainable Development	16
International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship	15
Desalination	7
Journal of Medical Engineering and Technology	7
Applied Energy	6
Renewable Energy	6
Energies	6
Energy	6
Journal of Sustainable Development	6
PLoS One	6
Sustainability	6
Energy Research & Social Science	4
International Journal of Gynecology and Obstetrics	4
International Journal of Social Entrepreneurship and Innovation	4
Sensors	4
Advances in Engineering Education	3
Environmental Science and Technology	3
119 Other Journals	141

2 Methodology

In this section, the methodology for searching the literature, selecting papers for further review, and classifying and coding papers are explained. This section is broken down into Sec. 2.1, which describes how relevant papers were chosen, and Sec. 2.2, which describes how relevant papers were classified.

2.1 Literature Review. The ultimate goal of this research is to help designers and researchers understand and locate relevant methods. This is done by classifying papers in the EGD literature so that designers and researchers can quickly access key information and sort through papers by several criteria. Classifying papers into categories by key criteria facilitates the sharing and application of design tools and methods [19,20]. Classification has been performed on the methods described in each paper. Papers may describe partial methods or multiple methods, and the same method could be described across multiple papers. Combining methods across multiple papers accurately would require knowing the intent of the authors or making large assumptions about the methods being classified. Therefore, the authors of this article did not combine methods from multiple papers into generic methods.

The PRISMA method was chosen for completing the systematic review of the literature [21]. The PRISMA method tracks and diagrams the identification and inclusion of papers for review, including papers from previous studies or papers added after the main review [21]. At each step, the number of records screened, included, and excluded are tracked including reasons for exclusion. See Fig. 3 for a visualization of this process as applied by the authors.

To understand what methods have been used by EGD practitioners, papers were selected from five pools. The first two candidate pools were articles in the *Journal of Humanitarian Engineering* and the *Journal of Development Engineering*. The next two pools of papers were papers originating from the ASME IDETC Engineering for Global Development Conference section and the IEEE Humanitarian Engineering Conference that were later published in an archival journal. The final pool of papers is from "Engineering for Global Development: Characterizing the Discipline Through a Systematic Literature Review" by Burleson and Austin-Breneman, which analyzed papers published by EGD Research programs listed in the Engineering for Change State of EGD North America Report [12].

These five sources were selected because these are sources that have identified themselves as being related to Engineering for Global Development. EGD is a broad and diverse field at the intersection of many disciplines. There are potentially hundreds of journals that could contain relevant material to aspects of EGD, but the authors felt that the most useful boundary to provide a focused set of papers to review was to start with sources that are specific to the EGD field. In addition, this means that the authors of this article did not have to make a judgment as to whether a paper was relevant to EGD and that the decision of relevance was made by the source of publication.

[2]design.byu.edu and https://ubwp.buffalo.edu/

In addition, as mentioned previously, the lack of widely accepted terminology in the field makes a keyword-based approach infeasible. No keyword term showed up in greater than 10% of the papers (see Fig. 1). Nonarchival literature sources were also not included in the scope of this article. The inclusion criteria for individual papers from the five paper pools were as follows:

(1) Publication in a peer-reviewed academic journal
(2) Published in the last 10 years
(3) Full text of the paper available in English

The initial number of papers from each pool is listed in Fig. 3. Applying inclusion criteria 1 and 2 reduced the initial combined pool of 1303 papers down to 392 papers. Applying inclusion criteria 3 and removing duplicates reduced the final number of papers to 374 [7,9,13,22,45–98,98–391]. The paper pool was determined and frozen on November 15, 2021, with no papers being added afterward.

The most prevalent reason for paper exclusion was a conference paper not having a related journal publication. The ASME IDETC conference sessions had 37 articles with no corresponding journal publication, and the IEEE GHTC conference sessions had 850 articles with no corresponding journal publications. The logical area for future research and insight could be for examination of the 887 conference papers with no corresponding journal articles. This could provide additional insights into additional global and diverse perspectives. Overall, the authors of this article believe that the set of 374 papers reviewed were relevant to EGD, provide valuable insights, and represent an extensive, broad, and diverse set of topics within EGD.

2.2 Coding and Categorization of Methods. Once the initial pool of papers had been reduced to the set of 374 considered papers, the authors determined what attributes would be relevant to use for the classification of each paper. The goal was to identify the most relevant and useful information to help designers and researchers find applicable design tools and methods. It was also imperative that this information could be ascertained through a reading of the paper without requiring additional research.

First, characteristics of methods that would be relevant to practitioners were identified from the authors of this paper's previous experiences as EGD practitioners and researchers and from similar types of literature reviews [11,12,392]. After creating a large initial set of potential categories, two trial classification runs using ten papers each were performed to determine if the candidate categories were both useful and able to be consistently identified. The following categories of attributes were identified by the authors of this article as relevant categories for classifying design tools and methodologies for social impact:

– Method purpose
– Qualitative, quantitative, or mixed Methods
– Input data used
– Paper setting
– Industry sectors covered
– Social impacts covered
– United Nation (UN) SDGs covered
– Contributions to the literature

Each category and its corresponding attributes are described in greater detail in Sec. 3. For each category where multiple options were available and options were not mutually exclusive, reviewers could select as many options as they desired, including all options or none if applicable. Once the classification criteria had been determined, the papers were then divided up among the authors to classify. This method of classification by rating papers along several criteria has been used in several cases, such as classification of methods for uncertainty management [393] and methods for architecting networked systems [394].

Each paper in the set of 374 was reviewed by two different authors of the present article, with the papers being randomly assigned to each reviewer assuring no reviewer was assigned a paper they authored. The order of the papers was also randomized to avoid bias due to the order of reviewing. Reviewers had access to the papers while reviewing and were able revisit and edit or correct any errors that had occurred during the classification.

Review by two reviewers allows for each paper to be reviewed by multiple reviewers with different backgrounds and experiences. Many of the categories and classifications depend on some level of judgement or opinion: such as what activities a method might be useful for or what individual impact indicators would apply to which Social Impact Category. This helped capture a broader classification that would not be as impacted by the individual opinions of reviewers.

It is important to note that reviewers were asked to classify the papers based on the information presented in the papers and not on outside knowledge. As an example, improved cookstoves may have social impacts on Health & Safety, Family, and Gender Impacts [395]. However, not every paper on improved cookstoves mentions these impacts. While the reviewers may have outside experience that they could use to extrapolate or make assumptions on information such as the social impacts covered, the authors have taken care to only use the information presented in the papers.

The categories and options used to classify each paper are listed in greater detail in Sec. 3. This information has been designed to be used to help researchers and practitioners select proper methods for their research. The results are presented in Sec. 4, with discussion presented in Sec. 5.

3 Attributes of Design Tools and Methods (Classification Categories)

This section describes the reasons for including each category in the classification. The individual attributes in each category are also described in greater detail. This is done for the purpose of demonstrating how the articles were coded as well as providing a list of defined terms to aid practitioners in interpreting the results of the systematic review. Categories and individual attributes may also be used for future classification of papers. This section is organized by subsections in the order listed in Sec. 2.2. The reviewers classified papers based on what information was explicitly included in the papers, but there were some papers that described methods that could be applicable to all options within a category but were not explicitly described as actually being applied to any. Having an option to include this as a possibility would be useful for future classification.

3.1 Method Purpose. This category breaks down papers by what design activities the methods in the paper would be used for. This type of breakdown has been used in previous reviews of social impact assessment and EGD literature [11,12,392]. Different parts of the design process require different activity types to acquire information, make decisions, or advance the design of a product. Breaking down papers in this way will make it easier to locate research containing relevant methods. The categories and definitions were defined by the authors after two rounds of preliminary classification activities.

– *Prediction Methods:* A method used to predict the impact or effectiveness of a product before launch.
– *Assessment Methods:* A method that measures or evaluates the impact or effectiveness of a product after launch.
– *Discovery and Exploration Methods:* A method used to help designers consider new social impacts or gain new insights into product stakeholders.
– *Ranking and Weighing Methods:* A method that helps designers determine the importance of different social impacts for a given product–stakeholder combination and make appropriate trade-offs.

- *Heuristics and Frameworks:* A method that provides general guidelines, considerations, approaches, or frameworks for improving the social impact of a product.
- *Technology Development Method:* A process designed specifically for developing or advancing the design of a specific product or technology.
- *Intervention Methods:* A method that focuses on the intervention accompanying a product including but not limited to: distribution, financing, policy, and the organizations running intervention efforts.

3.2 Qualitative, Quantitative, or Mixed Methods. Breaking down methods into qualitative, quantitative, and mixed categories helps designers and researchers understand the nature of the methods and their data. EGD involves factors that are easily quantifiable, such as material properties, heat transfer, and so on. It also involves factors that are harder to quantify such as human decision-making, product impacts on individuals, and design factors such as usability and individual preferences [396,397]. Integrating these factors can be crucial in understanding and representing these systems [398,399]. This classification helps researchers understand the methods being used and locate proper methods.

- *Quantitative:* Numeric data. Data that can be measured in units.
- *Qualitative:* Characteristic data, qualitative analysis, or would require quantification
- *Mixed:* A combination of quantitative and qualitative data.

3.3 Input Data Used. Classifying the data requirements helps designers and researchers understand the nature and the level of data required to perform methods in papers. EGD often involves new technologies, working with new populations, and gathering data about technology adoption and impact. Sometimes these data can be gathered from secondary sources and the work of others, and other times it is necessary to go gather data. Data requirements are of great importance for assessment and other methods [392]. In addition, data gathering can be often the most difficult and time intensive part of research methods [400]. This classification category helps designers and researchers understand the data requirements of methods on a basic level.

- *Primary Data:* Data that must be gathered by the team through experiments, observations, surveys, data synthesis, etc.
- *Secondary Data:* Data that can be acquired from existing sources.
- *No Data:* No data were required.

3.4 Global Regions and Areas Specified. The work of EGD occurs around the globe in a wide variety of contexts and locations (see Fig. 4). Some of this work may be specific to a given country, province, or city. Some work might be specific to urban or rural areas. Identifying areas specified in the paper helps those looking for area-specific information locate relevant research. Areas specified are broken down by both the global region and geographical zones specified. Individual countries mentioned in the papers were also tabulated but not used as major categories. The global regions are as follows:

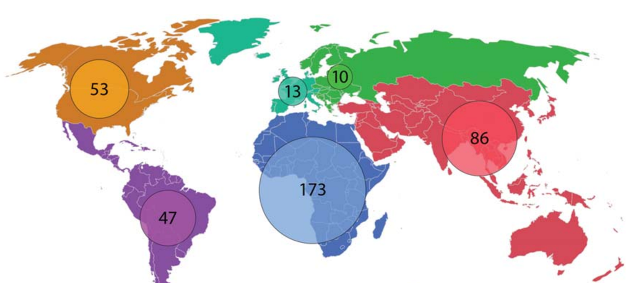


Fig. 4 Papers identified by location of project, as classified by one or more reviewers—meaning one or more of the people who reviewed and classified the paper

- *Africa*
- *Asia and Pacific*
- *Eastern European*
- *Latin America and Caribbean*
- *North America*
- *Western Europe*
- *None*

The geographical zones specified are as follows:

- *Urban*
- *Suburban*
- *Rural*
- *Wilderness/Natural Environment*

3.5 Engineering For Change Industry Sector. One common method of classifying engineering products is by sector or product category. Work done within a sector often deals with the same technical and social challenges faced by others in the same or similar fields. Researchers within a sector often publish in similar sources, utilize similar resources, and work in similar contexts. The options and definitions chosen for our classification by sector are those used by Engineering for Change[3]. Engineering for Change is an organization of more than one million professionals and maintains an extensive open source design database. Classifying papers into these sectors not only follows commonly used conventions in the field of EGD but also helps connect the literature to the resources provided by Engineering for Change.

- *Agriculture:* Related to the growth, processing, and distribution of plant and animal products.
- *Energy:* Related to the generation, distribution, storage, and use of energy from a variety of sources.
- *Habitat:* Related to the design, construction, and repair of housing and other infrastructure necessary for providing shelter for humans and building safe, resilient communities.
- *Health:* Related to improving human health through diagnosing, preventing, and treating disease through a variety of means such as improved sanitation, environmental health, nutrition, and access to medical devices.
- *ICT (Information and Communication Technologies):* Related to access to communication and information through a variety of technologies including digital means, mobile devices, sensors, software, etc. Related to leveraging these technologies for impact in other sectors. Related to ensuring fair, unbiased, and ethical use of these technologies for all.
- *Sanitation:* Related to improving living conditions through improved management of human waste, management of industrial waste products, and improved access to hygiene services and products.
- *Transportation:* Related to technologies and infrastructures that improve access and movement.
- *Water:* Related to technologies that improve access to, storage of, and quality of water.

3.6 Social Impact Categories. The Social Impact categories used are those identified by Rainock et al. [348]. These 11 categories were identified using an extensive literature review of both engineering and social science sources. These describe the effects that products have on individuals and society. Pack et al. interviewed more than 50 industry professionals about social impacts and found that most industry professionals focused on Health and Safety, with the major causes given in interviews including a lack of tools or processes for other social impact categories [10].

[3]https://www.engineeringforchange.org/

Categorizing papers by social impact categories will help researchers and practitioners find methods for all social impact categories and may aid in a broader inclusion of social impacts in design. Definitions for each of these categories come from Ottoson et al. [73]

- *Health and Safety:* Safety and security (real and perceived), activity/exercise, mental and physical health, mortality, improvement of life/health from product
- *Paid Work:* Earning potential, industrial diversification/change in economic focus
- *Stratification:* Social capital, inequality, introduction of new classes, social status, social mixing
- *Human Rights:* Human rights, respect for indigenous and minority rights, democracy/decision-making participation
- *Education:* Education, skills, empowerment
- *Family:* Alteration in family roles, structure, violence, stressors, ties, and role in society
- *Gender:* Gender roles, violence, stressors, inequality
- *Population Change:* Transiency of population, age structure, presence of seasonal population
- *Conflict and Crime:* Potential conflicts, crimes, increased or decreased substance abuse, potential of assault
- *Social Networks and Communication:* Impaired or improved personal relations, network's reliance on participation in decision-making process
- *Cultural Identity and Heritage:* Weakening/strengthening of values, norms, and beliefs, cultural intolerance, personality traits

3.7 United Nations Sustainable Development Goals.

The United Nations SDGs were set forth as a blueprint in 2015 to achieve peace and prosperity for the people and planet [401]. The SDGs have been recognized by over 70 countries and have been used as goals and blueprints for governments, NGOs, industry, and academia alike [402–404]. The UN SDGs are ubiquitous and categorizing the EGD literature by the SDGs improves the accessibility of the EGD literature to a broader community. Doing so also demonstrates what type of work is being done by the EGD community. Definitions come from the UN.

- *SDG 1 - No Poverty:* End poverty in all its forms everywhere.
- *SDG 2 - Zero Hunger:* End hunger, achieve food security, and improved nutrition and promote sustainable agriculture.
- *SDG 3 - Good Health and Well-Being:* Ensure healthy lives and promote well-being for all at all ages.
- *SDG 4 - Quality Education:* Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
- *SDG 5 - Gender Equality:* Achieve gender equality and empower all women and girls.
- *SDG 6 - Clean Water and Sanitation:* Ensure availability and sustainable management of water and sanitation for all.
- *SDG 7 - Affordable and Clean Energy:* Ensure access to affordable, reliable, sustainable, and modern energy for all.
- *SDG 8 - Decent Work and Economic Growth:* Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all.
- *SDG 9 - Industry, Innovation, and Infrastructure:* Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- *SDG 10 - Reduced Inequalities:* Reduce inequality within and among countries.
- *SDG 11 - Sustainable Cities and Communities:* Make cities and human settlements inclusive, safe, resilient, and sustainable.
- *SDG 12 - Responsible Consumption and Production:* Ensure sustainable consumption and production patterns.
- *SDG 13 - Climate Action:* Take urgent action to combat climate change and its impacts.
- *SDG 14 - Life Below Water:* Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
- *SDG 15 - Life on Land:* Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity launch.
- *SDG 16 - Peace, Justice, and Strong Institutions:* Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
- *SDG 17 - Partnerships for the Goals:* Strengthen the means of implementation and revitalize the global partnership for sustainable development.

3.8 Paper Contributions.

The final category for classification selected by the authors was paper contributions. Different papers have different purposes and contribute different things to the literature. Some papers provide knowledge and insights that others can use. Some describe methods, tools, or frameworks that can be used by others. The authors noted in the two classification test runs that it was hard to tell from the title and abstract of a paper whether the paper would simply recap a project, report widely applicable and useful results, or demonstrate a useful method. This category allowed reviewers to select what they believed were the major contributions of a paper so that designers or researchers searching the paper set can more easily locate the type of information they are looking for. The six category options created by the authors of this paper are as follows:

- *Knowledge about products.*
- *Methods, tools, frameworks, or models for products.*
- *Knowledge about stakeholders.*
- *Methods, tools, frameworks, or models for stakeholders.*
- *Knowledge about social impacts.*
- *Methods, tools, frameworks, or models for social impacts.*

4 Results

The results of the literature review yielded insights that provide a broad overview of the EGD literature, as well as a categorized, searchable, set of papers. This section will share the results of the classification and highlight some key insights and takeaways. Section 5 describes how researchers and practitioners can use the classified paper set to find their own insights, and Sec. 6 provides additional discussion and perspectives from the authors about the classified paper set and EGD as a whole.

Most of the insights in this section describe the distributions of attributes of the paper set for each category. The value of this information depends on the perspective of the practitioner. For example, if there were a large amount of papers describing assessment-based methods and a small amount of papers describing predictive methods, this might be exciting to those searching for assessment methods and highlight a potential research gap in the area of predictive methods. The breakdown of papers by UN SDGs might provide insights into what work is currently being done for those trying to gain a broader understanding of the EGD community, and highlight potential areas for collaboration with other disciplines. Not every distribution will be explored deeply, but we hope that these snapshots will provide useful insights and serve as a "jumping-off point" for deeper analysis and exploration. Please note that due to the possibility of multiple options being selected for a category that the percentages in graphs and figures will not add up to 100%.

Of the methods in the papers reviewed, 52% were found to be quantitative, 30% were found to be qualitative, and 25% were marked as having a mix of qualitative and quantitative data. Most papers required data of some sort, with 69% of methods using primary data acquired through experiments, surveys, or other data generated by the paper authors, 38% used some form of secondary data, and only 6% required no data at all.

Global regions specified provides insight into where the EGD work is being done. Of the regions specified, Africa was the most common, being mentioned in 40% of papers, followed by the Asia and Pacific Region at 19% and Latin America at 10%. North America and both Eastern and Western Europe all came in at less than 10% with values of 9%, 2%, and 2%, respectively (see Fig. 5). This contrasts with trends in authorship showing a majority of research published in the field comes from authorship in North America and Europe [12,392].

What these results do not tell us is whether papers that specify a global region or a geographical zone are specific only to that area, or if papers that did not specify a global region would be equally successful across all areas. Many papers in the set did not identify any specific region. There is benefit to researchers of both regionally specific and region nonspecific work, and the data set helps with identifying work that specifies both global regions and countries specified.

It was much less common for papers to specify if their intended application was for rural, urban, suburban, or natural environment setting. Thirty-six percent of papers specifically identified Rural Areas, with 11% identifying Urban Areas, 9% identifying Suburban Areas, and only 3% identifying the Natural Environment. This could be because the papers did not clearly present in which area or context a work was being provided or that the methods presented are general use across areas.

An overview of method purposes in Fig. 5 shows that assessment and technology were the most common method types, accounting for 37% and 27% of papers. Discovery and Exploration (26%), Heuristics and Frameworks (22%), and Prediction (19%) all accounted for a sizeable chunk. Intervention methods (9%) and Ranking and Weighing (4%) methods were the two lowest method categories, showing an opportunity for more development in these areas. A good quantity and variety of method types for different design activities suggests that the papers in the data set may be used throughout the entire development process.

An overview of methods by Engineering for Change sector in Fig. 6 shows the most common sectors to be Health (33%), Energy (31%), and Water (19%) followed by Information and Communication Technology (14%), Agriculture (11%), Habitat (7%), Sanitation (5%), and Transportation (2%). This category is useful for identifying papers and journals for EGD practitioners interested in working in a specific sector.

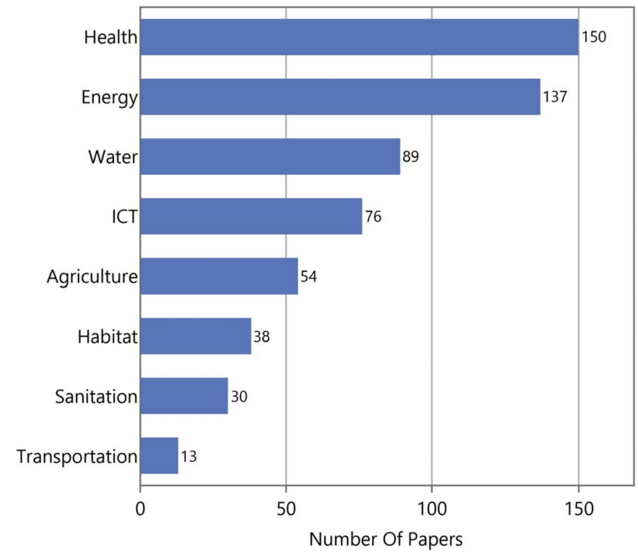


Fig. 6 Papers identified by engineering for change sector by one or more reviewers

The breakdown of papers by Social Impact Categories in Fig. 7 shows that 55% of papers covered Health and Safety Impacts. The next highest categories are less than a third as large, with Paid Work at 17%, Education at 13%, and Social Networks and Communication at 11% being the only other Social Impact Categories covered by more than 10% of papers. The knowledge that 7 of 11 Social Impact Categories are represented in less than 10% of papers not only shows the current main focus of EGD but also demonstrates the usefulness of a classified paper set that allows researchers to find papers that apply to these less common Social Impact Categories more quickly.

The breakdown of papers by the United Nations Sustainable Development Goal in Fig. 8 is valuable because many organizations around the world focus their work and goals on the UN SDGs. All 17 UN SDGs were covered by papers in the data set, with Good Health and Well-Being (40%), Affordable and Clean Energy (27%), Clean Water and Sanitation (23%), Industry, Innovation and Infrastructure (18%), and Sustainable Cities and Communities (17%) being the five most commonly identified SDGs in the paper set.

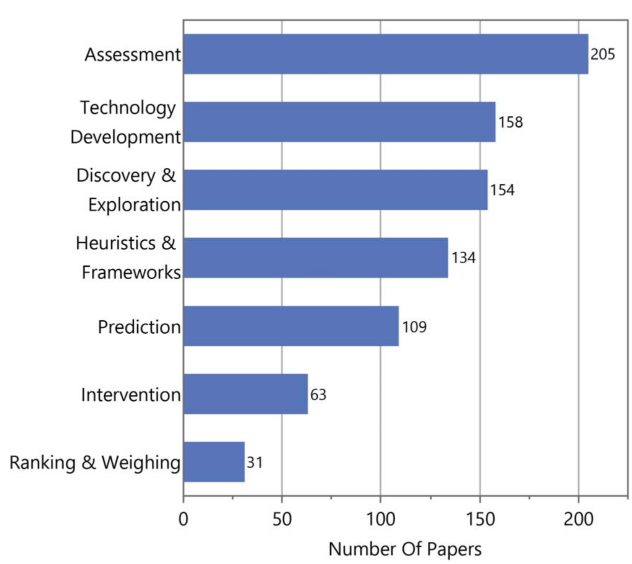


Fig. 5 Papers identified by method type by one or more reviewers

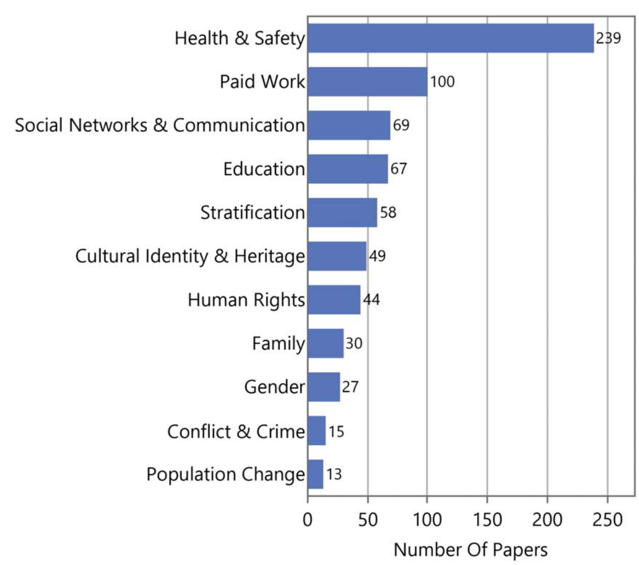


Fig. 7 Papers identified by social impact category by one or more reviewers

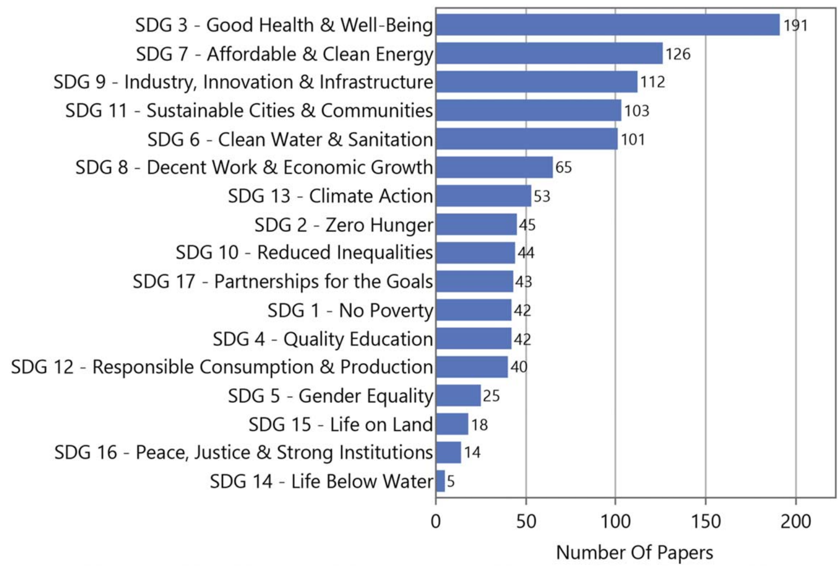


Fig. 8 Papers identified by unsustainable development goal by one or more reviewers

While looking at results by a single category is insightful, looking at how papers are broken down across multiple categories provides additional insights and further demonstrates the usefulness of a classified paper set. Figure 9 shows a breakdown of papers by method purpose and Engineering For Change Sector. One striking feature of the graph is that at the intersection of smaller sectors and method purposes, the number of papers covering both a desired sector and a desired method purpose quickly becomes quite small. This trend is also observed in Fig. 10, which charts method purpose by Social Impact Category, and Fig. 11, which charts method purpose by UN SDG.

Looking at multiple categories also helps identify trends within a category. For example, looking at method purpose by sector, we can see that the reviewer responses identified prediction methods nearly twice as much as in Energy (60) than in Health (32) despite Health having more papers overall. This shows that the Energy Sector is using prediction methods a lot more than other sectors. Both the Health and Water Sectors have a high proportion of assessment methods compared to other sectors.

Looking at the distribution of papers across the 10 years the data set covered (2012–2021) provides insights into the growth of EGD and into general trends. Figure 12 shows the number of papers published each year. We see a trend of general growth year over year, with a peak of papers in 2018. It is important to note that one of the major subsets of data, papers from "Engineering for Global Development: Characterizing the Discipline Through a Systematic Literature Review", only goes up until 2019. In addition, the set of papers was compiled on November 5, 2021, which means that 2021 is missing the last 2 months of the year. So that may explain some of the drop-off in growth. Regardless of the overall drop-off, a linear fit model gives a growth of 2.5 papers per year. The overall growth between 2012 and 2021 is up over 50%.

Adjusting category totals by the number of papers published each year, a linear fit was used to determine any trends occurring over

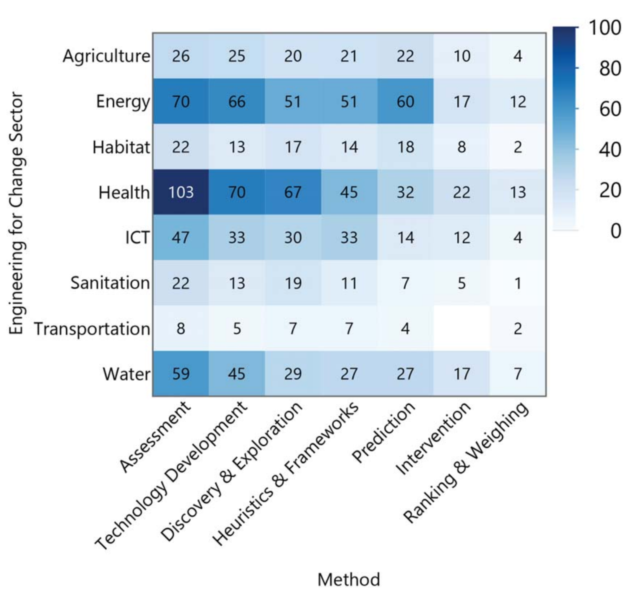


Fig. 9 Papers identified by method type and by engineering for change sector by one or more reviewers

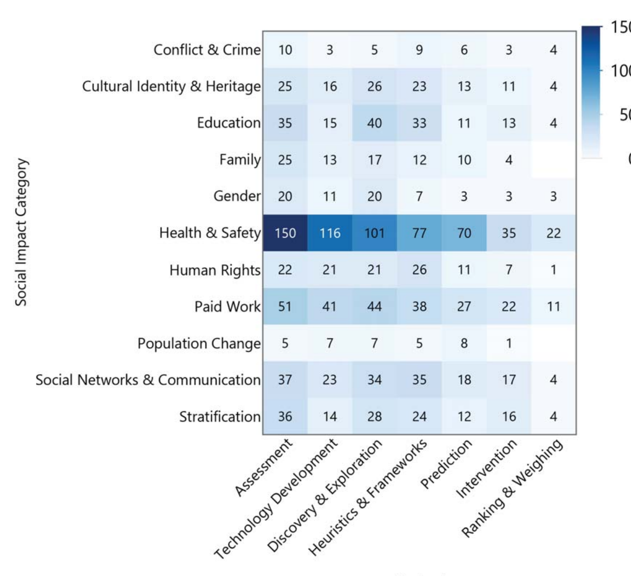


Fig. 10 Papers identified by method type and by social impact category by one or more reviewers

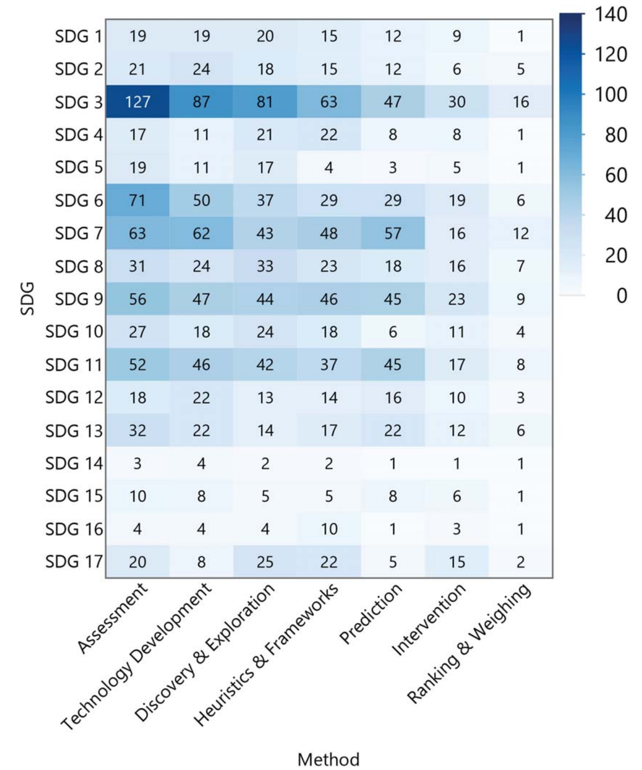


Fig. 11 Papers identified by method type and by United Nations sustainable development goal by one or more reviewers

time. Only three models demonstrated an R^2 value greater than 0.7 were a decrease in papers not requiring data, a decrease in papers related to UN SDG 17 Partnerships for the Goals, and an increase in papers that were viewed as contributing product models, tools, or frameworks.

A decrease in the amount of methods that did not require any type of data demonstrates an increased standard over time. The increase of papers contributing product frameworks, tools, or methods also shows an increased use of modeling of products.

The lack of significant trends related to method type, industry sectors, social impact categories, and the majority of the UN Sustainable Development Goals suggests that growth and change

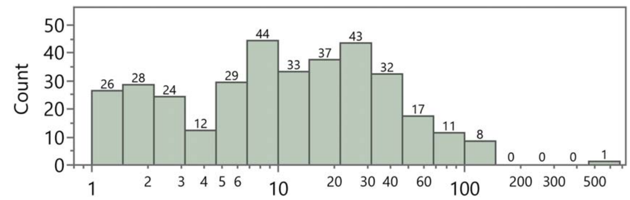


Fig. 13 Histogram of the number of citations in the paper corpus, log scale

may be happening at individual institutions and groups in diverse ways, as opposed to a single convergent direction across the EGD discipline.

Figure 13 shows the breakdown of papers by the number of citations. The mean number of citations is 20 with a standard deviation of 36. The first quartile range is 3, median is 9 citations, third quartile is 26 citation, and the 90th percentile is 47. Of the 374 papers in the data set, 1 paper eclipsed 500 citations and 9 papers had 100 or more citations. The data presented suggest that there are a low number of citations of these papers. This may be attributed to diverse research paths within the field, or several efforts across disciplines using different key terms or language, indicating authors may not be accessing all of the research that is relevant. The diversity of this field lends itself to a variety of approaches across disciplines. The variety of approaches strengthens the collective advancement of the field and the extent of the impact may be furthered through accessibility of these approaches.

The classified paper set offers opportunities for other designers and researchers to locate relevant methods and perform their own analysis. This paper set includes classifications for all papers, as well as the paper authors, publication year, journal name, number of citations, keywords, and abstracts for all papers.

5 Using the Classified Paper Set

The variety of papers in the classified set cover different method types, social impact categories, sectors, data requirements, and use contexts. The true benefit of the classified data set is it allows designers and researchers to quickly locate papers using multiple criteria. For example, a designer who wanted to predict the education impact of a solar micro grid in a rural area would need to find a paper that satisfies a method type, sector, impact category, and geographical zone simultaneously. Such a paper exists in the paper set,

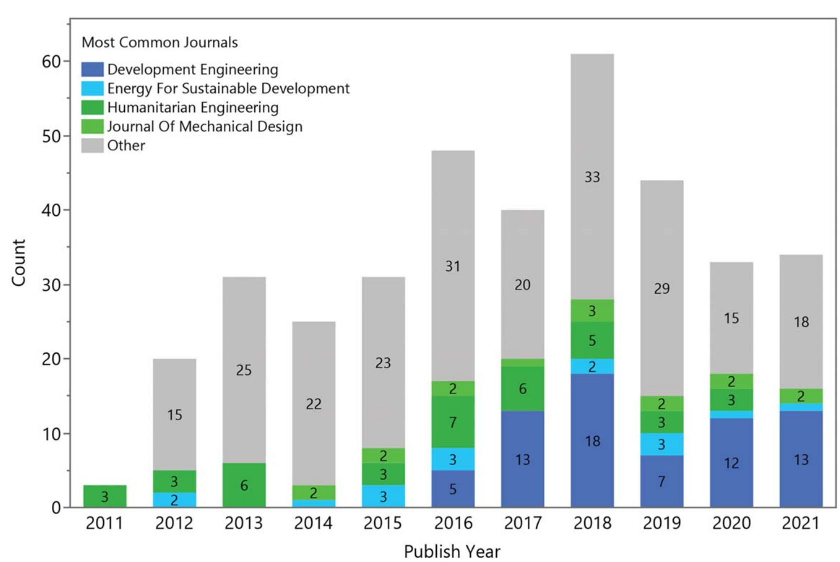


Fig. 12 Papers published by year 2012–2021

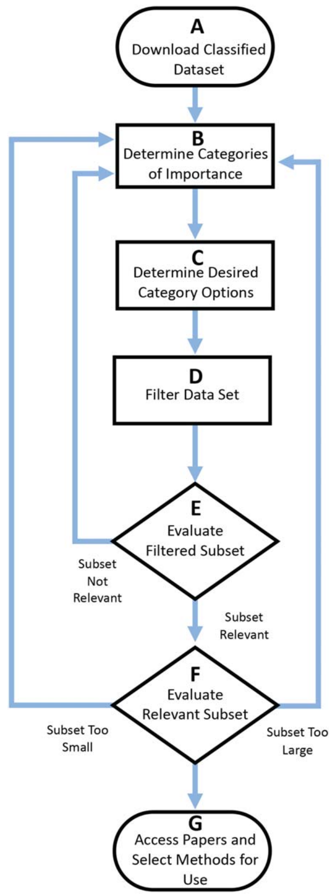


Fig. 14 Using the classified data set

but does not show up in a keyword search using terms for all four criteria previously mentioned [30].

This section describes how to use the classified data set to locate relevant papers. Figure 14 shows a flowchart that walks through this process. The steps for using the classified data set are as follows:

(1) Download the Classified Data Set
(2) Determine Categories of Importance
(3) Determine Desired Category Options
(4) Filter Data Set
(5) Evaluate Results
(6) Access Papers and Select Methods for Use

5.1 Download the Classified Data Set. The full set of classified papers will be available for download[4]. Both coded and noncoded versions will be available. Papers will be listed by row and classification by different categories and options by column. In addition to the classification information, the datasheet also includes the full title of each paper, keywords, abstract text, author names, journal of publication, year of publication, and number of citations (as of February 5, 2022).

The noncoded version will list the categorization for each paper with strings of words in each cell of a spreadsheet. This version is easier to search through manually. The coded version will be a CSV file that uses 1s and 0s for each category option with a 1 indicating a category option is applicable and a 0 indicating an option is not applicable. A data dictionary indicating which columns indicate which options is also available and recommended for download.

5.2 Determine Categories of Importance. The next step in locating relevant papers is determining which categories are most important. These categories along with their subsequent options will be used in future steps to filter down the classified set of papers from 374 papers to a smaller more focused set.

The authors recommend initially selecting two to three categories of importance for use in filtering the data set. Selecting too many categories may result in narrowing down the paper set too much. Using too few categories may result in too large of a subset of papers. Categories may be added or subtracted in later steps, but best results occur from a proper selection of category.

The papers are classified by nine different categories, which are detailed in Sec. 3 of this paper. The categories and reasons why the categories may be of important are as follows:

– *Method Purpose:* This category is important when designers are looking for methods that could be used for a specific design activity or stage of design.
– *Qualitative, Quantitative, or Mixed Methods:* This category is important if the designer is specifically looking for methods that are qualitative, quantitative, or mixed.
– *Input Data Used:* This category is important for designers who are reliant on specific data sources.
– *Global Region:* This category is important when designers believe that their work or the impacts of their work are specific to the area of the world they will be implemented in.
– *Geographic Area:* This category is important when differences between zones such as urban, suburban, or rural will likely have substantial differences in the type of work being done.
– *Industry Sectors Covered:* This category is important when designers know they will be doing work within a particular sector.
– *Social Impacts Covered:* This category is important if designers are interested in social impacts of a specific type as opposed to social impact in general
– *UN SDGs Covered:* This category is important when designers are interested in work related to a specific UN Development goal.
– *Contributions to the Literature:* This category is important if the distinction between papers that give specific knowledge versus papers that describes general methods is important.

5.3 Determine Desired Category Options. Section 3 describes each category and category options. The authors again recommend starting with one to two options for categories of importance. Additional category options can be added to expand subsets later if necessary.

5.4 Filter Data Set. Once category options have been selected, designers can filter down the data set, and create subsets using the options previously selected. Doing so will lead to a smaller subset of relevant papers.

5.5 Evaluate Filtered Subset. At this point, designers will have a smaller subset of papers. There are several ways to determine if this subset of papers is acceptable. If the number of papers is too large, it is recommended that additional categorization options are selected to further filter down the subset of papers. If the number of papers is too small, it is recommended to remove categorization options until the subset is large enough. If after accessing the papers, if the papers appear to not be relevant or applicable, it is recommended to select different categories or category options for filtering

5.6 Access Papers and Select Methods for Use. Now that the set of 374 papers has been filtered down to a focused set of papers, designers can search for the papers by title using the academic search of their choice. The authors of this paper recommend that as designers read through the papers they take notes and pay particular attention to the methodology and results sections of each paper. These notes will help designers determine the pros and cons of the

[4]design.byu.edu and https://ubwp.buffalo.edu/esdrg/

methods presented in each paper. Designers may choose to use the methods presented in a single paper, combine methods from multiple papers, or use the papers from the data set as guidance for the creation of new methods.

5.7 Additional Uses for Data Set. In addition to improved searchability, the paper set is also a useful jumping-off point exploring the literature. Looking across a single category such as sector can expose designers and researchers to the breadth and variety within that area. For example, a designer in the agriculture sector going through the list sorted by agriculture might be surprised to see social impact categories not previously considered, or method types outside of what they typically use. They might be exposed to works published in journals they were not aware of or using data sources they had not used before. Doing exploratory literature searches using typical search engines or databases can be time consuming and require wading through irrelevant sources to find useful sources. This curated, classified paper set not only makes looking for specific information easier but also improves exploratory searching.

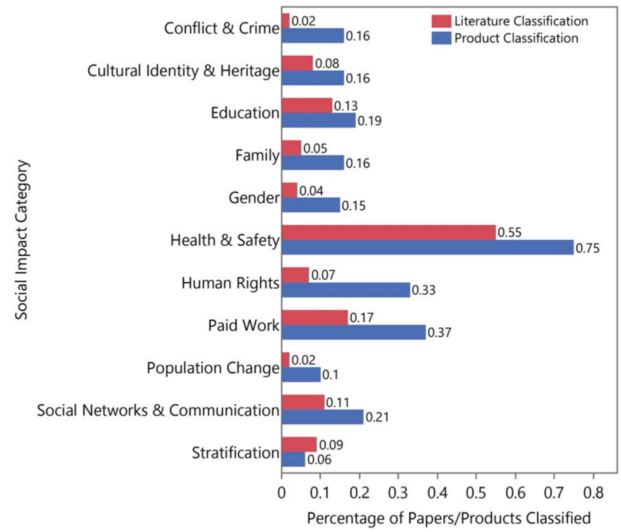


Fig. 15 Expected impacts from products versus impacts identified in paper set

6 Discussion

The 374 papers reviewed represent the breadth and depth of the work being done in EGD. Papers reviewed covered every sector, every social impact category, and all 17 UN SDGs. The variety and novelty of the work being done in the field of EGD stood out to the reviewers, who were exposed to work they had not encountered in their previous years of research and involvement in the field. While searching for relevant EGD publications has historically been challenging, the authors have found that there is published research describing valuable methods of various purposes across all sectors and in all areas of social impact. Classifying this information into a searchable paper set will allow designers and researchers to more easily identify papers with relevant design methods and tools for working in an EGD context. Broad insights into EGD observed during the classification of the paper set are discussed in Sec. 6.1, and opportunities for future work are discussed in Sec. 6.2.

6.1 Insights Into Engineering for Global Development. The variety of papers demonstrates that there are many different approaches taken in EGD research. Some papers simply described a product, others assessed an intervention, and others included validated social impact models, and so on. While specific approaches may be viewed by some people as more valuable, more rigorous, or more telling, there is no indication from the review of an optimal, or even desired path to EGD work. This alone may be an indication that standards, expectations, or paper types need to be articulated within the community.

Another major theme that stood out was that while the literature represented a breadth of sectors, social impacts, and sustainable development goals, the depth varied greatly by area. For example, Health and Safety was represented in 55% of papers, but other social impacts were represented in much lower percentages such as Gender at 4%, Conflict and Crime at 2%, and Population Change at 2%.

If we compare the frequency that social impacts occurred in the paper set to the frequency that social impacts were found in a review of 150 products by Ottosson et al, we see that impacts were present in the literature at significantly lower values than we would expect to see (see Fig. 15) [73].

However, if we compare the frequency that social impacts occurred in the paper set with the relative frequency of social impacts discussed over 46 interviews in a paper by Pack et al., we see very similar levels of consideration across the social impact categories (see Fig. 16) [10]. This shows a correlation between impacts considered in industry and academic research.

The sectors and impacts that were considered most were those that intersected with well-established fields of engineering such as the energy sector, water and sanitation, and the medical device sector. Increased collaboration with other fields such as the Social Sciences could improve the level of consideration of social impacts outside the most common categories such as Health and Safety.

In addition, much work is being done across various fields of engineering that applies to the different sectors and impact areas where EGD is working in. For example, eight of the ten most highly cited papers in the dataset were published in journals such as *Energy* and were applicable to well-established fields of engineering. It is important that the EGD community look to and collaborate with the state-of-the-art research in technical and scientific disciplines as well as the Social Sciences.

6.2 Future Work. The papers in the set were spread out across a large number of journals and used disparate keywords. Furthermore, keywords in the paper set often only pertain to one or two aspects of the paper. For example, it is common for a paper to have a sector term, a product term, or a general development related term, but not all three at once. The addition of sufficient and consistent keywords to easily identify social impact categories, method purposes, or UN SDGs would be a useful practice to help designers and other researchers to locate relevant literature.

In addition, many social impact categories are underrepresented in the literature. Papers that include the intersection of specific social impacts, method types, and sectors are severely underrepresented. Year-by-year analysis showed a lack of increased consideration of these area proportional to papers published. EGD as a community could better consider these areas.

In addition to the information that the authors were able to identify, there are other pieces of information that would be useful for researchers and practitioners to have. The authors attempted but were unable to classify papers based on:

How long methods in the paper would take to complete
Fidelity of methods in the paper
Generalizability of methods in the paper

If this type of information could be consistently identified, it could be useful in selecting the most appropriate method for a given design context. For example, if a designer was working in the energy sector and wanted to predict gender impacts, they could look for methods specific to that area. However, if such

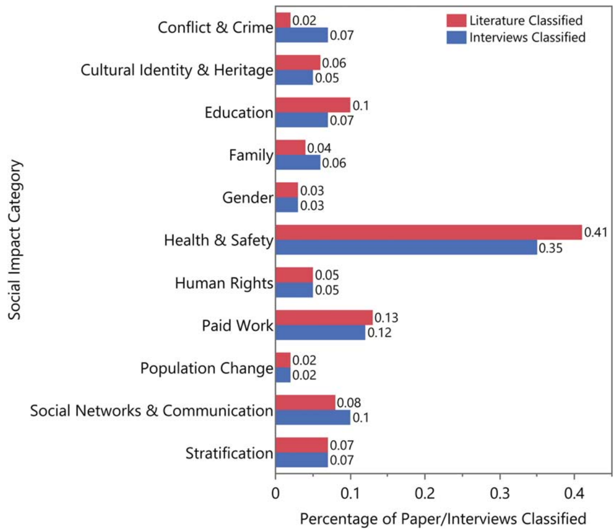


Fig. 16 Impacts identified in paper set versus impacts discussed in industry interviews

methods did not exist, they could look for prediction methods in the energy sector methods that were generalizable across impact categories, or gender impact prediction methods that were generalizable across sectors. In addition, knowing beforehand the fidelity of a method and how long it would take to complete would help practitioners select the most appropriate method for their context. This information would be difficult to accurately assess, but if future classifications could accurately identify it, that would add additional value to designers and researchers. However, most papers did not present sufficient information to accurately assess across the entire paper set.

The majority of the papers focused on their individual context and the results of their process. The methods they used are described throughout in sufficient detail to describe the research. Often times, however, this level of detail and purpose of message do not lend well to identifying and following methods. This type of information may be presented in other types of publications such as white papers, books, training manuals, and videos. Those sources, however, are not as easily searchable as academic literature. One potential practice would be to reference instructional materials in the academic literature to help researchers locate material that would allow them to better replicate methods, tools, and best practices.

Future work related to this study could look at subsequent publications from the authors in the paper set to gain insight regarding the sustainability of the outcome, and thus utility of the method used for integrating social concerns into the problem. An additional step could be to reach out to some of the authors in the paper set and solicit their feedback to help understand if the reviews performed for this paper captured the intention of their work.

The intersections of EGD is both a challenge and an opportunity as we seek to engage in cross-cultural, cross-disciplinary areas. As engineers seek to tackle the "wicked problems" present in societal challenges it will take seeking understanding through experience, research, and key collaborations [405].

We have presented an analysis to support researchers in EGD. This is realized through the review of the literature and by elucidating the emerging themes from the analysis. Not only do the results of this research allows for researchers to find papers that may be helpful but it also illustrates the trends and ways forward in EGD.

7 Conclusion

The work that has been done over the last 10 years represents a growing field doing important work. It is intersectional and spread across a variety of industries and reported in a variety of sources. The literature holds a wealth of knowledge, wisdom, experience, and useful tools and methods to those who are able to navigate the literature and identify useful information. The data set, classification methods, results, and discussions presented in this article aim to aid in navigating the literature to identify and use relevant information. The data set, which is available[5], has the title, abstract, and classifications for all 374 papers considered in this review. As EGD continues to grow, we hope that it will do so in ways that continue to expand out into new horizons and are increasingly easy to navigate and use.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data and information that support the findings of this article are freely available.[6]

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