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Striving for Energy Autonomy? An Empirical Investigation of Homeowners' Drivers and Barriers to Participate in Community Energy Systems in Germany

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Abstract
Despite extensive political funding programs, the energy consumption in Germany for space heating and hot water stagnated on a high level of 870 TWh over the past few years and even exceeded the level of 2010. To reduce consumption and meeting the energy-efficiency goals set by the German federal government, an option for private homeowners is to participate in community energy systems (CES). However, homeowners' reluctance to join CES constitutes a major issue. Recent research has not provided deeper insights into reasons for this hesitation. Focusing primarily on local district heating systems, we use two theoretical approaches, motivation and attribution theory, to shed light on drivers and barriers in the decision-making process of homeowners. To gain insights, an explorative research design was chosen, and 22 problem-centered interviews were conducted with homeowners as well as experts.Our results show that subjectively perceived energy autonomy can be a barrier for private homeowners to participate in CES. Furthermore, we find a discrepancy between objective energy autonomy, as defined from a technical perspective, and homeowners' perception. Regarding this, the two major aspects shaping homeowners' perception of energy autonomy are (1) perceived independence from third parties as well as other external influences, and (2) a sense of control over the home energy system and its costs. Our study provides new insights into the decision-making process of homeowners to participate in CES. Additionally, we identified several implications in how far practitioners can address subjectively perceived energy autonomy issues to reduce inertia to join CES.

Keywords: Energy Autonomy, Community Energy Systems, District Heating, Private Homeowners, Decision-Making Process, Consumer Research

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Introduction

Climate protection represents one of the main challenges of the 21st century. To reduce harmful carbon emissions, a restructuring of the German energy sector is required. Although considerable achievements have increased the share of renewable energies in the power supply sector, the transition to more energy saving in the heating sector lacks severely behind (Schubert, 2016). The energy consumption for space heating and hot water stagnated on a high level of 870 TWh over the past few years and even exceeded the level of 2010 (Dena, 2019). In this context, private households account for approximately two thirds of the total energy used in Germany. To reduce consumption and meet the energy-efficiency goals set by the German federal government (BMU, 2018), a need for sustainable heating solutions for communities and neighborhoods has emerged (Riechel, 2016).

By implementing cogeneration technologies (characterized by generating power and heat), decentralized solutions are capable of providing cross-sectoral energy supply to local communities. These so-called community energy systems (CES) do not only include production and distribution of energy but also consumption and prosumption (Koirala et al., 2018). In the specific context of heat supply for local communities, a shift from individual, fossil-fueled heating to district heating contributes to energy efficiency as well as sustainable energy supply (Werner, 2017; Lund, Möller, Mathiesen, & Dyrelund, 2010). Local district heating systems (in the following referred to as district heating) distribute heat from local energy sources through pre-insulated pipes for (space) heating and domestic hot water (preparation) in urban and rural neighborhoods (Frederiksen & Werner, 2013). To provide future communities with these viable heating services, an integration of (low temperature) heat sources is necessary, e.g. industrial waste heat or renewable heat such as solar thermal (Lund et al., 2014). Therefore, CES inevitably move closer to citizens (Local Energy Consulting, 2020).

However, residents' resistance and lack of willingness to participate in CES still constitute major challenges (Büscher & Sumpf, 2018; van Veelen & Haggett, 2016; Raven, Mourik, Feenstra, & Heiskanen, 2009). This is especially the case for district heating, as it requires a minimum number of consumers to operate profitably. In Germany, only 6.6% of the residential building stock is connected to district heating, with individual fossil-fueled heating like gas and oil still leading clearly (BDEW, 2019). In the literature approaches to explain the drivers and barriers are often derived from a sociological perspective, concentrating on community issues (Koirala et al., 2018; Li, Birmele, Schaich, & Konold, 2013) and applying theories on social movements (Bomberg & McEwen, 2012). Although these studies reveal several important drivers of residents' participation in CES, i.e. bottom-up planning processes (Young & Brans, 2017; Li et al., 2013; Allen, Sheate, & Diaz-Chavez, 2012) and community trust (Kalkbrenner & Roosen, 2016; Walker, Devine-Wright, Hunter, High, & Evans, 2010), the underlying reluctancy to connect to district heating has not been clarified in more detail so far.

Recent research focuses mainly on economic aspects and financial incentives to motivate homeowners to connect to district heating (Østergaard & Svendsen, 2019; Burlinson, Giulietti, & Battisti, 2018). Despite extensive political funding programs by the German federal government, the willingness to connect remains low, even though

district heating can present a more cost-efficient and comfortable alternative for private homeowners. Therefore, the questions arise why private homeowners refuse to connect to district heating and how they can be activated to participate in CES.

As a possible explanation, we aim to investigate a rather unexplored construct in the context of CES, namely the concept of perceived energy autonomy. Derived from research in the field of residential heating systems, studies show that homeowners' preference for independence, e.g. from fossil fuels and energy suppliers, plays a significant role in the decision-making process, besides factors like costs and comfort (Karytsas & Theodoropoulou, 2014; Michelsen & Madlener, 2013). A study conducted by Koirala et al. (2018) shows that energy autonomy can also have a significant effect on citizens' willingness to participate in CES. In this instance, it is defined as the idea of being independent from a national grid and big energy suppliers. We refer to it as energy autonomy at a community level. Nonetheless, when it comes to individual homeowners' perception, we assume that autonomy may constitute a barrier for participation. Following two theoretical approaches, motivation and attribution theory, we aim to shed light on this construct and provide new insights in homeowners' decision-making to connect to district heating.

Conceptual Background

In the context of energy transition, the term autonomy is predominantly examined from a technical perspective (Gawali & Deshmukh, 2019; Fedak, Anweiler, Ulbrich, & Jarosz, 2017). Rae and Bradley defined energy autonomy as "the ability of an energy system to function fully without the need of external support" (Rae & Bradley, 2012, p. 6499). Yet most studies do not define the label autonomy clearly, so that it is often used synonymously with the term autarky (Deutschle et al., 2015). Regarding CES, degrees of autonomy can be calculated in order to estimate the coverage of local energy demands by local supply options (Rae & Bradley, 2012). In technical literature, there are traditional methods to determine a technology mix (e.g. on individual building-scale) that fulfils the autonomy demand, such as storage systems in order to bridge time gaps between (renewable) supply and consumption (Köthe, 1982). These multi-technology energy systems require large investments as well as space which is limited in urban areas. In general, self-sufficiency for single buildings is often neither technically expedient nor economically profitable (Bracke, Tomaschek, Brodecki, & Fahl, 2016). In addition, autonomy does not represent a main goal, particularly in CES when implementing improved (renewable) energy systems in neighborhoods (Protogeropoulos, Brinkworth, & Marschall, 1997). Nevertheless, several studies exist researching ways to develop completely energy-autonomous houses (Brosig & Waffenschmidt, 2016; Storch, Leukefeld, Fieback, & Gross, 2016) or (on a larger-scale) islands (Kaldellis, Gkikaki, Kaldelli, & Kapsali, 2012). Although being completely autonomous is a technical challenge and trying to be independent from common supply system can oftentimes be economically inefficient, a general propensity towards autonomy can be identified among homeowners (Bracke et al., 2016; Klein, 1983).

Motivational Perspective

In the context of energy saving investments, independence/autonomy is defined as a consumer motive that shapes private homeowners' decision-making to invest in energy

saving measures (vom Hofe, Frensemeier, & Holzmüller, 2016; Jager, 2006). In studies analyzing homeowners' decision between different residential heating systems, it is described as homeowners' preference to be independent from fossil fuels, politically motivated supply crises and fluctuating energy prices (Michelsen & Madlener, 2013; Claudy, Michelsen, & O'Driscoll, 2011; Decker, Zapilko, & Menrad, 2010). Further investigations show that homeowners with a preference for being independent from fossil energy sources are more likely to choose an individual heating system, e.g. a heat pump (Karytsas & Theodoropoulou, 2014; Michelsen & Madlener, 2012). Considering different small-scale cogeneration technologies, independence is considered as a relative advantage increasing homeowners' willingness to pay for wood pellet boilers and solar panels. Homeowners believe that these heating systems will make them more independent from energy providers and their houses more self-sufficient, while also reducing the dependence on fossils like gas or oil (Claudy et al., 2011).

Another finding is that there seems to be a discrepancy between perceived and objectively existing energy autonomy. In a qualitative study examining private homeowners' motives to purchase photovoltaic, Sonnberger (2015) found out that homeowners acknowledge the misperception that the installation of solar panels fosters their independence. However, the "feeling" of being self-sufficient is deemed to be satisfying. Regarding this misperception of autonomy and its potential role as a barrier in the context of CES, we use a second theoretical approach to examine perceptual differences between subjective and objective autonomy.

Attributional perspective

Based on Heider (1958), attribution theory describes how individuals make sense as well as predict other peoples' behavior and events by attributing causes to them. The theory was expanded by Weiner (1985) who classified causal attributions according to three dimensions: (1) locus (internal vs. external), (2) stability (stable vs. variable), and (3) controllability (controllable vs. uncontrollable). In the cause of this investigation, we concentrate mainly on the locus and controllability dimensions. First established by Rotter (1966), the concept *locus of control* describes the degree to which a person perceives a certain event as a consequence of his own behavior or the result of external forces. Furthermore, individuals with an internal locus of control believe that their actions have an influence on their environment, and they can exert control over it (Weiner, 1985). If individuals tend to perceive themselves as controlled by external forces, they are less convinced to have certain degrees of freedom regarding their choices for action and would choose a lower level of action identification (Förster, 2014). Action identification is related to the same called theory by Vallacher and Wegner (2014), in which different levels of personal agency have been determined. According to these levels, one has to differentiate between high-level agents assigning their acts to larger meanings of action and low-level agents thinking of their acts in regard to details as wells as means of action (Vallacher & Wegner, 1989).

Although attribution theory was mostly used to investigate interpersonal relationships (human – human), recent studies began to apply this theoretical approach to examine non-interpersonal relationships (human – non-human), like human's adoption of technical systems (Alony, Hasan, & Paris, 2014). An application to CES and private homeowners' adoption of district heating, has – to the best of our knowledge – not been studied so far.

Methodology

Since the construct of subjectively perceived energy autonomy remains largely unexplored so far, we used an explorative research design to gain deeper understanding of the underlying structure of dimensions and factors of the construct (Homburg & Giering, 1996). Hence, qualitative techniques are deemed as suitable, since they provide information about individual attitudes and underlying motives (Misoch, 2015).

In a first step, problem-centered interviews (Witzel, 1982) with 14 homeowners were conducted. The number of interviews was determined according to the principle of theoretical saturation (Strauss, 1991). To gain different insights and ensure heterogeneity amongst the interviewees, purposive sampling was performed (Patton, 2009). Private homeowners were selected for interviews, who (1) live in an urban neighborhood and are/were already connected to district heating or (2) plan to replace/have already replaced their heating system within the future/last years. These two categories of interview partners are used to examine various aspects of energy autonomy with regard to different heating systems and decision-making situations. For the first category, we selected three urban neighborhoods in the Ruhr area in Western Germany. The interviewees were personally contacted. The examination area in terms of CES is of particular interest due to the influence of an extinct mining industry. Therefore, former collieries' houses still exist in this area with homeowners who are still using coal heating because they receive concessionary coal. Participants of the second category were acquired by posting in discussion groups on social media. The interviews were conducted personally or via telephone with an average duration of 37 minutes. The sample contained six female and nine male participants with an age variation between 37 and 69. A semi-standardized guideline was used (Hopf, 2010) and improved iteratively after each interview as well as slightly adjusted to the different circumstances.

In addition, eight semi-standardized interviews with experts were conducted. Interview partners we selected had long-term experience in customer service and operated in locations concerned with the implementation of heating systems. Interviews were carried out with energy consultants (who focused on heating systems), energy suppliers (with business projects concerning district heating), heating engineers, consultants for finance and business models for community energy projects and an architectural advisor. The average interview duration was 55 minutes.

Next, we recorded, transcribed, and analyzed all interviews using the commercial software tool MAXQDA. To interpret the findings, qualitative content analysis was applied (Mayring, 2015), and a category system was developed following inductive coding (Kuckartz, 2009). To meet high quality standards of qualitative research, several measures were taken. Credibility was increased by using multiple method triangulations (Flick, 2004). Interview material as well as the coding system was reviewed several times to fulfill intracoder-reliability (Mayring, 2015). A detailed description of the investigation process was used to ensure transferability.

Results

Subjective energy autonomy as a barrier to participate in CES

A major finding of our exploratory study is that subjective energy autonomy can be a reason for the failure of implementing CES. It can lead to homeowners' reluctance to connect to district heating, because they perceive it as becoming dependent, on e.g. neighbors, resulting in a loss of control over the energy system. Energy consultants and heating engineers named several examples of failed projects due to homeowners, perceiving CES as a less autonomous solution compared to their individual fossil-fueled heating. One of the interviewed homeowners described a family member, living in the same neighborhood, who refused to connect to district heating, although subsidies were provided: "I told him, listen to me, do it now, it is never going to be cheaper than now […] But no, I want to regulate the heating myself and all this stuff he has told me." Participants even spoke of the idea to become entirely autonomous by insulating their houses, deploying ground source heat pumps, and installing solar panels on the roof: "If a house is energetically self-sufficient, this is what I think is great. I think this would be a nice asset […] I would definitely pay a premium for it." The idea of being more autonomous can even outweigh rational motives like economic ones, causing irrational decision-making.

Facets of subjective energy autonomy

Based on the various insights given by the participants, we brought up a working definition of the examined construct: *Subjective energy autonomy presents the individual perceived state of self-determination over one self's energy supply, and further on having a sense of control over the energy system, and its costs*. Categorizing the interview material via qualitative content analysis two dimensions of subjective energy autonomy were identified: (1) Independence as an external perspective, and (2) control as an internal perspective (Figure 1).

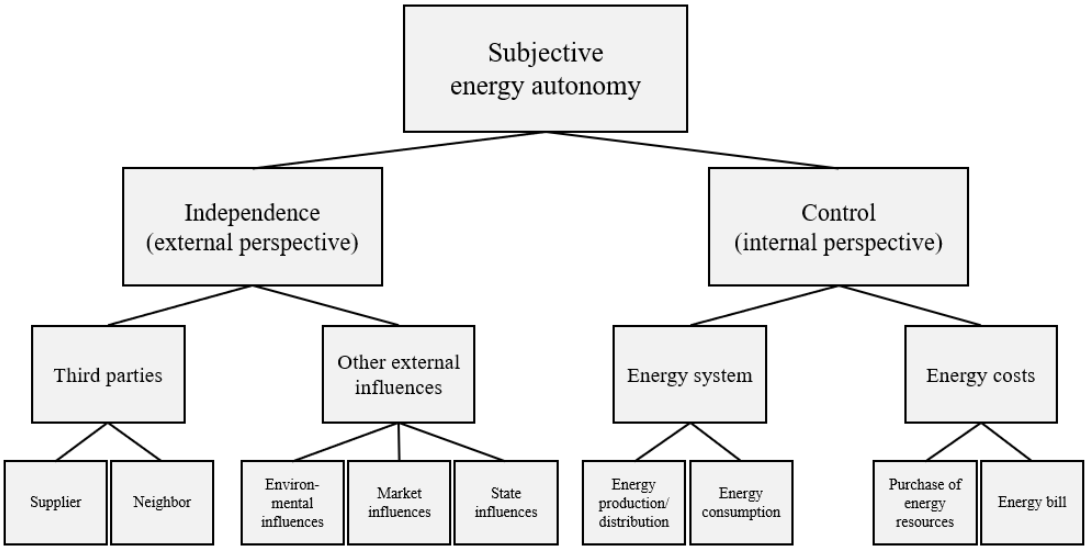

Figure 1: Conceptualization of the construct of subjective energy autonomy (Source: own illustration)

Independence (External perspective)

The aspect of independence was mentioned several times by the interviewees. It depicts the perception of homeowners to make decisions over the energy supply without the influence of third parties (e.g. suppliers, neighbors) as well as other external impacts. When it comes to being independent from suppliers one must differentiate between (1) CES owned by citizen-cooperatives, and (2) CES owned by energy suppliers. In the first case, when the energy production and distribution is in the hand of residents, CES can be seen as becoming more independent from energy suppliers and, thus, present a driver for such projects. In the second case when an energy supplier is involved in the business model, it can become a barrier and individual forms of residential heating would be preferred. In this context, a strong reason against district heating were long-term contracts: "What really bothered us […] was the dependence on one supplier that you have no alternatives to later on and that you are at the mercy of the supplier when it comes to price policy." Owners of district heating systems set up contracts for approximately ten years during which homeowners are required to consume heat, otherwise the connections would not be profitable for the operator. In addition, the operator of district heating often holds the position of a local monopolist, as there are usually no alternative suppliers operating in the distribution network (*supplier-lock-in*). An implementation of several district heating grids in one community would be inefficient.

Another core aspect mentioned was the perceived dependence on neighbors. When starting a cooperation with neighbors to install a CES, trust issues need to be considered. Some of the interviewed homeowners can imagine sharing an energy system with a family member or close friend, but not a neighbor. Even if a district heating system was operated by a professional company, trust issues do play a role: "There was an opportunity that they put the pipelines through the property of our neighbor into our basement connecting it to our heating system, but we did not want that, we wanted our own connection, because what will happen if there is going to be an argument with the neighbor in the future." In the expert interviews it was also mentioned that the perception of being dependent on neighbors, whether it is on a technical level or in form of a contract (case of mutually owned grids), raises difficulties regarding personal conflicts and trust issues.

Another factor that was brought up by the interviewed homeowners was the independence of other various external influences, such as market influences, like fluctuation of oil and gas prices. Some interviewed homeowners said that with fossil heating systems one is less autonomous due to the dependency on fluctuations of market prices as well as other environmental influences. Others perceived this circumstance in the opposite way, thinking they are in the position to determine when they want to buy energy resources like oil and liquid gas. Thus, they believe that they can exert control over prices (shown in Figure 1 as control over purchase of energy resources), causing a higher degree of perceived autonomy for fossil-fired heating compared to district heating. This leads us to another dimension of subjective energy autonomy, which concentrates more on an internal perspective.

Control (Internal perspective)

The aspect of control deals with homeowners' perception in how far they can exert control over the energy system as well as its costs. When it comes to the technical control over the energy system, interviewees argued that the perceived level of energy autonomy of a heating system would be higher if they (a) have a 100% ownership of the system and (b) the system is physically located in the house. The underlying idea is that with an oil or liquid gas tank the energy production as well as distribution is located on the property. An expert working as an energy supplier for district heating in rural areas describes the situation as follows: "I want my oil. It is the generation of 'war children' saying, I own what I sit on." The fact that oil needs to be imported is not taken into consideration. However, when taking different heating systems into account, where purchases of energy resources are needed like oil, liquid gas or even pellets, varying degrees of the perceived level of autonomy can be observed: "Oil heating, assuming that you have a tank, would be kind of more autonomous […] but not like wood-fired heating." The given reason was that the stock of wood resources is located near the house and can be acquired way easier in an emergency.

The last aspect mentioned includes the perceived control over energy costs. Part of the perceived level of energy autonomy was associated with a feeling of financial control over energy costs. One of the energy consultants talked about her longtime experiences with customers concerning energy bills when sharing heating systems: "So, everyone has the fear that they are not able to bill energy costs separately anymore […] I think it is very extreme how strong their need for an own energy bill is." In this context, it was also mentioned that some homeowners are even willing to pay more than to pay for somebody else. In most cases, however, it is an irrational fear since separate heating meters are installed.

"Mismatch" between subjective and objective energy autonomy

Another finding of our study is that there is a clear discrepancy between the objective degree of energy autonomy of a heating system and how it is perceived by the interviewed homeowners. One of the interviewees with a former coal-fired heating system stated: "So, I'd like to tell myself that I want to be self-sufficient. So, I was self-sufficient with my coal heating, because I could fill coal in the oven myself. I could pick a haulage company myself. I could observe the market a little bit." Even though, individual fossil-fired heating is not self-sufficient from a technical perspective due to the dependence on (international) suppliers. Some of the interviewed homeowners with fossil-fired heating systems on individual building-scale perceived such systems as more autonomous than district heating.

In general, the perceptions of autonomy differed across the interviews. Homeowners who stated energy autonomy means to be completely independent of third parties and other external influences rated geothermal solutions as highly self-sufficient, but also said that for example fossil heating systems, like oil and gas, are less autonomous than district heating. Others purported that having the energy system located in their houses (e.g. in the case of oil or liquid gas tanks), increased their control over it and, thus, the degree of autonomy.

Discussion

Our empirical study revealed various new insights into the construct of subjectively perceived energy autonomy. This construct can shape private homeowners' decisions to participate in CES, such as district heating. Delving deeper into the different facets of subjective energy autonomy, we found that it can act as a barrier in the decision-making process to connect to district heating. Prior studies on this topic refer to autonomy as a driver for the participation in CES controlled by residents (Koirala, Koliou, Friege, Hakvoort, & Herder, 2016; Bomberg & McEwen, 2012). In addition to this, we found out that subjective energy autonomy can also be a barrier, due to the emerging perception of becoming dependent (e.g. on neighbors). In this context, homeowners fear losing control over the energy system as well as losing financial control because they assume a collective energy billing. Regarding studies on district heating stating that heating systems should be motivated economically (Østergaard & Svendsen, 2019), our results extend these findings by demonstrating that private homeowners' decision to connect to district heating is not a pure investment decision. Homeowners may assess residential heating systems and district heating based on subjective energy autonomy. Interviews showed that even if a community energy solution presents a more cost-effective alternative, private homeowners may reject it and chose an energy system that is more costly but has a higher degree of perceived energy autonomy instead.

Regarding the different facets of energy autonomy, several results of our study are in good alignment with findings of recent research. In the literature homeowners' preference for independence from suppliers and price fluctuations of fossil fuels plays a significant role when choosing a residential heating system (Michelsen & Madlener, 2013; Claudy et al., 2011). These aspects of independence were also mentioned by our interviewees. An additional finding in our research is the *supplier-lock-in* situation which can act as a barrier for homeowners to connect to district heating. District heating businesses in Germany commonly set up contracts for approximately ten years (e.g. in new-built neighborhoods). This lock-in of consumers by long-term contracts "creating natural monopolies" was also mentioned by Burlinson et al. (2018).

One of the major findings of our investigation is that there is a difference between objectively existing and subjectively perceived energy autonomy. This misperception can also be found in studies focusing on homeowners' decisions to implement solar panels (Sonnberger, 2015). In this context, attribution theory can provide possible explanations. Referring to the concept of *locus of control* (Weiner, 1985; Rotter, 1966), homeowners with an individual fossil-fueled heating, i.e. coal, oil or liquid gas, may have an external locus of control. Following this assumption, they perceive events as controlled by external forces and think that they have no or less control over certain events. Taking the levels of personal agency into account (Vallacher & Wegner, 1989), these homeowners may choose lower levels of action identification, such as residents who depict low-level actions like "filling coal in the oven" themselves and "picking a haulage company" on their own as actions symbolizing autonomy.

Practical Implications

From our findings, several practical implications can be drawn for marketers as well as technicians. Besides well-structured communication strategies that increase

transparency and inform private homeowners about a new CES, several other aspects need to be considered. For example, we recommend developing strategies in order to balance negative effects of the *supplier-lock-in* situation. This can be achieved by designing contracts in such a way that prices and their increase are fixed so that homeowners have no fear of an arbitrary price policy by the operator. When it comes to private homeowners' concerns of being dependent on neighbors, following suggestions might work: (a) In communities in which an energy network or plant is owned together with other local residents, contingent liabilities should be clarified. (b) In communities where an energy network is operated by an energy supplier, homeowners should be informed that connections to the grid are technically separated as well as billed separately from neighboring houses (e.g. by offering information events and consultation). Public meetings in the neighborhood such as round tables can not only help to clarify misunderstandings and eliminate incorrect information, they may also help to build trust between neighbors and prevent future conflicts. This implication is also in line with the findings of van der Schoor and Scholtens (2015) that a high level of joint activities as well as a shared vision are crucial to strengthen *local networks*.

Regarding the technical set-up of district heating systems, a recommendation is to provide each homeowner's building with its own pipe connection to the main network instead of attaching pipes that are located on a neighbors' property. Besides using information instruments, promotion could help to position district heating as gateways to become independent from finite resources and price fluctuations of fossil fuels in the long run. Considering the discussion on banning of fossil heating in certain areas, district heating can also guarantee a certain level of independence from future political regulation steps as it already fulfills high energy-efficiency standards. Another opportunity for marketing campaigns would be focusing not primarily on individual energy autonomy, but on autonomy at a community level which covers demand through local sustainable energy production.

Conclusions

Our study represents a novel step in the research field of CES by providing insights into the rather unexplored construct of subjective energy autonomy, its underlying dimensions and factors. In this context, we contribute to recent research by conceptualizing the construct of subjective energy autonomy through qualitative techniques and extend the concept from a motivational and attributional perspective. Furthermore, our findings shed more light on homeowners' drivers and barriers when participating in CES.

Regarding limitations of this investigation, a sample of 22 qualitative interviews provides (individual) in-depth insights. Therefore, our results should not be generalized too much. Further studies should conduct quantitative research in order to analyze the effect of subjective energy autonomy on homeowners' willingness to participate in CES with a larger sample size. The results of our study are a basis for conceptualization and operationalization for those future projects. In addition, several other factors (e.g. comfort, energy safety, ecological motives) should be simultaneously included when investigating homeowners' decision to join CES from a consumer research perspective.

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Get Out of Your Comfort Zone: Externalization in Architecture to Increase Social and Environmental Connectivity

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Abstract

Buildings currently account for 39% of energy-related carbon dioxide emissions annually, worldwide. Despite the acceleration of climate change, architecture is increasingly designed as hermetically sealed boxes, requiring increased conditioning, which in turn further contributes to the greenhouse gas emissions warming up our planet. In addition to disassociating people from the natural environment, this also creates spaces where people disconnect from their community, and live within boxes both physically and socially. Though current research addresses many environmental and human health concerns that arise from internalized architecture, it does not address the social disconnection nor is there any specific terminology and research that focus on externalizing programming as a strategy. To fill this gap, this synthesis establishes important terminology and research to support 'externalization', and explores the environmental and social impacts of externalizing programs through both design evaluation and morphology. Through thorough literature review, case studies research and analysis, the importance and impacts of externalization is defined. Then an externalization taxonomy is developed to support designers in two ways – as a design evaluation tool and as a design support for integrated architectural design and innovation that would better demonstrate how externalization can create integrated designs that provide layers of environmental, social, and health benefits while reducing the total building energy demands. Especially in the context of the current pandemic (COVID-19), externalization is evermore important. The synthesis provides the necessary groundwork to allow for externalization to be researched further, and provide designers the necessary framework to shift towards externalized design approaches.

Keywords: Externalization, Sustainable Living, Climate Change, Social Sustainability, Architecture

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Introduction

Currently the challenge is twofold- there is increase in designs where spaces are disconnected from the outdoor environment, which not only has energy demand and environmental implications, but also health and wellbeing implications. Second, by designing internalized spaces that disconnect people from the outdoor environment, designers have also created socially disconnected spaces that are not conducive to increased social interaction. Without the ability to hear neighborhood chatter and noises of the community from outside our window, people gain increasing levels of isolation, and lose a sense of belonging within their local communities. Loss of community vibrancy and a lack of diversity in terms of interactions between occupants, and an understanding result in a sense of insecurity and anonymity within the neighborhood that can greatly affect the social and cultural vibrancy and resiliency of communities.

For environmental connectivity, externalization provides building performance and energy savings, biophilic benefits for health and wellbeing, and biodiversity benefits for the environment. In terms of building performance and energy savings, robust research on passive design strategies (Wang et al. 2014), mixed mode design (Loftness 2014; Loftness and Haase 2013; Watson 2013; Liebard and Herde 2009), and daylight and thermal autonomy all increase the overall environmental connectivity while reducing the overall energy demands. Dynamic envelope design is crucial as architecture becomes increasingly flexible based on weather conditions and activity levels as it reduces the energy demand of the building, but also provides alliesthesia (thermal delight) to the occupants. Furthermore, simulation softwares enable designers to further explore the potentials of integrated passive designs to best balance between the indoor and outdoor environments given local contexts.

Another benefit of increased environmental connectivity is increased biophilic benefits in terms of occupant health and wellbeing. Biophilia is a human's innate biological tendency to seek connection with nature, which can have emotional, mental, and physiological impacts on our wellbeing. Based on Edward O. Wilson's biophilia hypothesis, biophilic design focuses on designing in connection with nature (Wilson 1986). Notable research by Stephen Kellert and Bill Browning solidified the importance of biophilic design within architecture, as well as highlighted its impact on human wellbeing (Heerwagen, Kellert, and Mador 2008; Browning, Catherine, and Joseph 2014; Terrapin Bright Green 2012). For example, several studies indicated that connection to nature could lower tension, anxiety, anger, fatigue, and confusion, and could positively influence mood and self-esteem (Alcock et al. 2014; Barton and Pretty 2010; D. K. Brown, Barton, and Gladwell 2013). Biophilic design supported the connection of humans to nature encouraged the strengthening of indoor-outdoor relationships as there are studies that indicate that application can provide both biophilic and environmental benefits to architectural practice (Dreiseitl 2019).

Lastly, increased environmental connectivity can support local biodiversity through regenerative design or the creation of nature corridors and hotspots. In research by Hes and Du Plessi, regenerative design that focused on designing for local ecologies helped rejuvenate damaged ecosystems (Hes and Plessis 2014). This encourages for a close relationship between occupants and nature. Given growing climate change and biodiversity concerns, ecologically driven approaches become increasingly important.

The integration of nature and porosity within architecture can support the migration and growth of flora and fauna within an urban setting, providing both occupants biophilic benefits while also allowing nature to have spots of habitation amongst the urban concrete jungle (Jain 2019).

Building program externalization also contribute to enhanced social connectivity, which can reduce isolation, improve community cohesion and vibrancy. In January of 2019, the Health Resources and Services Administration issued the "Loneliness Epidemic", which notes that nearly 1 out of 3 older Americans now live alone, which can result in serious mental and physical health effects (Health Resources & Services Administration 2019). "Loneliness and social isolation can be as damaging to health as smoking 15 cigarettes a day", and thus serious actions need to be taken to address this concern (Health Resources & Services Administration 2019). Though spatial conditions are not the sole contributor to the loneliness epidemic, there are studies that support the impact of spatial conditions on isolation. Social capital is also a growing research topic, as social connectivity becomes a growing concern within predominantly urban design (Putnam 2020). However, what are the building level implications when there is minimal social connectivity, when one cannot open the window to hear children playing, when there is not a porch where people can interact in passing? How has the internalized approach to architecture started to discourage social interaction and connectivity, and what impacts and implications it may have? These questions are explored to varying degrees by researchers, though there exists a missing link between externalization and social connectivity.

This thesis links both environmental and social connectivity, and establish why designing for externalization would be better than the current internalized approach. Especially now in the context of COVID-19 pandemic and social inequity, what role can externalization play? Existing research already support the importance of externalization as people lean towards balconies, porches, and other externalized spaces that allow them to regain connectivity in a forced disconnected environment due to quarantine (Ottoni et al. 2016; Martin 2020; Nisenson 2020). Additionally, flexible boundaries such as sliding doors or outdoor classrooms enable schools to continue teaching while enforcing safe distancing, which are all enabled through externalized design (Bellafante 2020; Superville 2020; Couzin-Frankel, Vogel, and Weil 2020). Given this new context, externalization grows in value as we become increasingly aware of the disconnectivity of existing spaces. With improved social connectivity, study also show its impact on safety and wellbeing within lower-income communities, as spaces designed often don't encourage social interaction or allow for community identity to develop (Saegert, Winkel, and Swartz 2002; Knapp et al. 2019). This can greatly affect vulnerable communities, which can lead to more severe mental and physical health impacts due to poor ventilation, lack of access to nature, etc.

Externalization Palette

First set of criteria is the environmental connectivity of building programming - based on how the space is sealed, how much daylight is available, and what kind of activity takes place in these spaces. The worst scenario is a space that is fully sealed with full mechanical support and no access to natural daylight. Then the introduction of natural daylight opportunities while remaining fully sealed and full mechanical support is the

next improvement towards environmental connectivity. With the introduction of versatility, the dynamically sealed spaces allow for added operability and access to passive strategies and natural daylight. Then externalized low function spaces introduce fully externalized transitory spaces. Lastly, the most amount of environmental connectivity represent fully externalized high function spaces where social living spaces would be fully externalized. Considerations for environmental connectivity could result in a significant amount of energy savings due to the decrease in conditioned internalized space. Additionally, this allow for an increase in physical activity and circulation, which can increase the overall social connection. Through environmental externalization, there is added visual richness and connectivity, and well as auditory and sensory richness. This allows for the community to gain a sense of vibrancy through architectural design.

Second set of criteria is the social connectivity of building programming, which focuses on the amount of social connectivity that the space enables for its occupants. The most socially disconnected is individual and disconnected spaces. Then it moves onto individual but visually connected spaces, which are typically spaces with glass facades where you can see, but not hear or interact. Then it moves onto the building community, which allows for the occupants within a building to socialize and interact with one another. It then moves onto higher levels of public engagement with the neighborhood community connection and finally the urban community connection where it is fully open to the public. The increased social connections allow for the success, resiliency, and longevity of the externalization strategies through increased social connections, an increase in the amount of outdoor activities, and allow for increased socio-cultural richness. Additionally this encourages people to communicate and develop a level of tolerance through a sense of community, which can increase the community resiliency in times of crises such as the current COVID-19 pandemic.

When both the environmental connectivity and social connectivity are overlapped, it creates a larger palette that can then evaluate architectural design through this color schema - The Externalization Palette. The palette allows for immediate understanding of a design's externalization quality in regards to its social and environmental considerations and creates a set of vocabulary for building program externalization that can then evaluate architectural design through the criteria of environmental and social connectivity. Architectural design can then be evaluated through this palette to better understand the externalization quality of a design through this evaluation color palette. This palette is arranged so that both criteria must be considered during evaluation as both levels of connectivity determines the quality and effectiveness of externalization in application, and diversity in the types of connectivity within a design is also crucial to its overall success. This palette does not seek to over-simplify the depth of spatial quality and social spaces, but aims to better consider the multiple layers through a more defined set of criteria and vocabulary. In doing so, a better understanding of building program externalization could be reached, and result in more appropriate applications of externalization in architectural design practice.

Externalization Taxonomy

The externalization taxonomy is a series of fifty strategies that help support designers when thinking about externalization in architectural design, it doesn't serve as a comprehensive list or a copy-paste solution, but as a series of potential inquiry sparked by existing design strategies stemming from prior case study research. However behind each strategy generated within the taxonomy also lies deeper literature review and research that support the importance and value of the strategies generated. The full taxonomy can be divided into the following four broad categories:

- Externalize Circulation
- Externalize Family
- Externalize Community
- Embrace Ecology

Each category contains several externalization strategies, each of which includes an explanatory diagram, a description, scientific research that supports the environmental and social benefits of the strategy, and a precedent study that utilizes the specified strategy. The layout of each taxonomy is shown in Figure 1. These strategies will not be shown in this paper itself, though are accessible online.

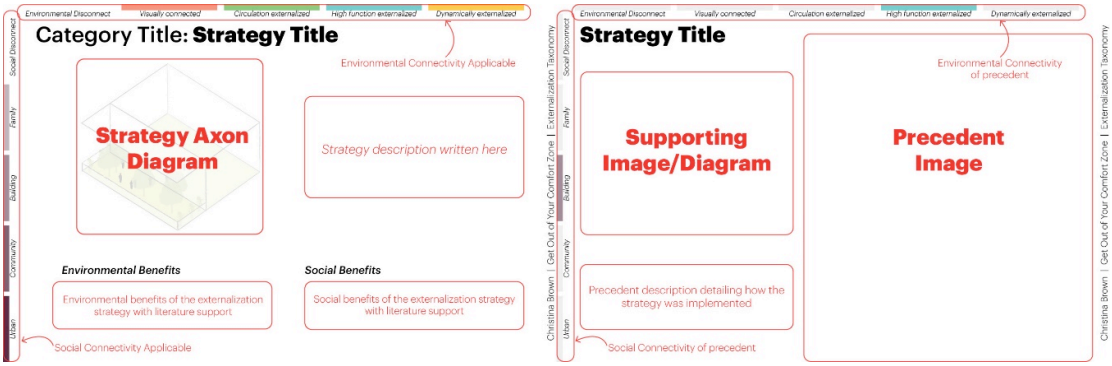

Figure 1: Externalization Taxonomy Layout

Externalization Taxonomy to Support Design

How can designers could use the 50 externalization taxonomies in design - and what are the qualitative and quantitative benefits of implementation? Four specific strategies were chosen and applied to a case study in Pittsburgh to better understand its impact on the building's design, its daylighting and energy performance, and lastly its experiential impact. The four specific strategies chosen where the shutter facade, dynamic facade, periphery social, and terraced garden strategies. These four strategies were applied to the Environmental Charter School (ECS) in Garfield to explore the value of externalization in architectural design.

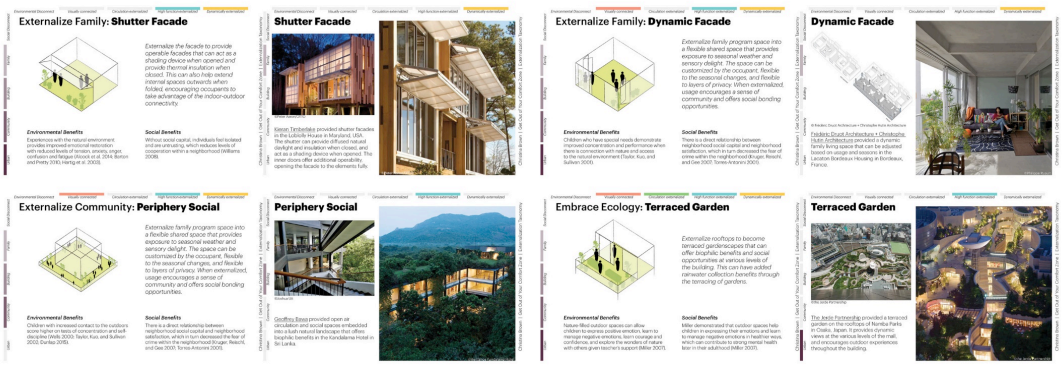

Figure 2: Four Externalization Strategies Applied to ECS

The existing ECS building is an enclosed building with thick brick wall construction due to how old the building is. The window sizes and overall building performance was enhanced with the renovation prior to the school's opening, though all windows in the building are inoperable to the outdoors. This results in a fully internalized spatial experience that does not encourage students and school staff to experience and connect with the outdoor environment despite the school's out-the-door learning approach. Analyzing the current baseline, the school is primarily enclosed with 71.8% of the total school providing visual connection to the outdoors alone (in red) as shown in Figure 91. The paved area on the southern side of the school as well as the parking lot on the northern side of the school is used for students to play, which is 6.3% of the total program area and the only area that is high function externalized to the outdoors. Due to the lack of greenspace located on the site itself, the adjacent open greenspaces (both located on steep hills that prevent easy access) as well as parks further away are relied on. Spatially and architecturally, the baseline does not allow the school to take advantage of the outdoor environment at all. The school follows a standard educational layout with a central circulation and classrooms facing both the north and southern facades, and the building is three stories tall. The school building does not contain a traditional gym space, so the activity room on the ground floor (a larger classroom area) along with the outdoor spaces are used in lieu of the gym space. Physical activity is crucial to children's physical and mental development, making the importance of the outdoors evermore important due to the lack of gym space for physical activity. Given the evident limitations to the baseline ECS building, how can externalization provide valuable impacts to the experience and performance of the existing architecture? This is explored in increasingly more drastic applications – starting with the shutter façade externalization strategy from the externalization taxonomy.

The shutter façade aims to externalize the façade to provide façade operability that can act as shading devices when opened while providing thermal insulation when closed. When opened, the shutters can provide shading and rain/snow coverage to allow for use as long as temperature is permitting. This can also help extend internal spaces outwards when folded, encouraging occupants to take advantage of the indoor-outdoor connection. Passive strategies such as natural daylighting and natural ventilation can also be utilized with this approach. The use of the shutter façade allows the building externalization ratio to shift from a predominantly internalized space to primarily dynamically externalized space (73%). The amount of environmentally disconnected and high function externalized spaces do not change however due to the strategy mainly influencing the building façade design alone.

However, the northern and southern outdoor areas are landscaped to provide improved outdoor areas that had better encourage students to play outside. Additionally due to the inclusion of the shutter façade, the ground floor classrooms are able to spill out to the nearby greenspaces due to the operability of the design. This approach does not greatly affect the cafeteria or circulatory experiences of the school, but given that students are spending most of their time in classroom settings, this approach can still have profound impacts with biophilic benefits for the students and faculty at ECS. Furthermore, due to the shading provided by the shutter when opened, the natural daylight simulations indicate great levels of spatial daylight autonomy (83.1%) while having very little possibilities of glare. This means that classrooms could take advantage of natural daylight strategies without worrying about issues of glare, which is especially important for the classroom experience given that issues of glare usually deter school staff from taking advantage of natural daylighting opportunities as much. Blinds are still available given that the use of projectors and other technologies may require the classroom to be fully dark at times, though the opportunity to use natural daylighting rather than artificial lighting will have profound impacts on the student's wellbeing as well as the operational costs of the school as a whole.

In addition to the natural daylighting benefits that resulted from the shutter façade, the overall building energy use intensity (EUI) also is impacted. Due to the use of natural daylighting and natural ventilation strategies, the total building EUI would be as an astonishing 24.17 kBtu/ft^2/year. This is only slightly above the 2030 EUI Target for educational buildings. Given the use of passive strategies that would reduce existing cooling, heating, and lighting loads, it results in the equipment becoming the highest energy load for the whole building instead. Additionally, using Cove.tool, a simple cost analysis was conducted to see the various renovation options possible, which aims to calibrate between the amount of money spent relative to the building's energy performance. As shown in Figure 196, the lowest cost bundle is making no further changes from the design iteration, though for $1,321 the energy could be optimized even further, resulting in a less than 2-year payback and a 2% energy savings.

Another strategy with greater alterations to the baseline is the dynamic facade, which provides even more porosity and flexibility into the architectural design. The dynamic façade externalizes internal program into a flexible shared space that can provide exposure to seasonal weather changes and provide sensory delight. The space can be customized by the occupant and allow for layers of privacy. When externalized, the usage encourages a sense of community and offers social bonding opportunities. Given the strategy and climate type, a dynamic buffer zone is also added on the southern facade to take advantage of thermal capture in winter months. This strategy allows for mostly dynamically externalized spaces, but increases the amount of high function externalized spaces through balconies. This results in great increases in teachable area, social area, and playable area through the added buffer space and balcony additions. Due to this implementation, there is 73% dynamically externalized building community space, and a combined total of 8% circulation externalized and high function externalized spaces. There is still a significant amount of internalized spaces in the center of the building, though it does improve slightly from the original baseline building externalization ratios (BER). Additionally in this iteration, unlike the shutter façade, there are programmatic and spatial impacts. With the implementation of dynamic façade, there is a 24% increase in the total teachable

areas, a 109% increase in the total social areas, and a 79% increase in the total playable area. This is due to the inclusion of balcony spaces and the dynamic buffer space. This strategy delivers a very different connection to the outdoors for the students given that this strategy acts more like layers of indoor-outdoor-ness (much like an onion), while still providing many of the externalization benefits that the shutter façade offered.

In terms of daylight performance, this iteration provided even higher spatial daylight autonomy (sDA) of 94.9%. However, this also resulted in increased annual sunlight exposure (ASE) of 28.3%. The increase is to be expected given that this strategy does not offer shading solutions, so additional shading strategies could be explored to address the visual comfort concerns. Similar to the shutter façade, the dynamic façade also had a similar EUI value of 24.39 kBtu/ft^2/year. Moreover, like the previous iteration, the equipment load is the main dominant load for the whole building energy use intensity breakdown. However, unlike the previous iteration, the cost analysis showed that significant energy savings could be made with actually less cost. This indicates that the design of the school provided more energy savings with less construction and system costs. The most optimized bundle offers a $26,730 reduction in cost for an added 3% energy savings, which would result in immediate payback!

The third strategy is the terraced garden, which aims to embrace ecology while offering both social and biophilic benefits. Terraced garden aims to externalize rooftops and facades to become terraced gardenscape that can offer biophilic benefits and social opportunities at various levels of the building. This can have added rainwater collection and other ecological design strategies integrated into the design process. In this iteration, there are terraced landscapes west of the building that embraces a bigger outdoor play area for the students. The parking lot is in return moved offsite to the adjacent open space. The southern paved area is now transformed into a flexible garden space and outdoor kitchen space with balconies on the second and third floors. This approach greatly increases the amount of high function externalized spaces, with the majority of the design being either dynamically or fully externalized to the outdoors. This also results in incredible increases in the total teachable area (41%), social area (159%), playable area (297%), and circulation in the outdoors (154%). In this iteration, the BER shifts from a predominantly dynamically externalized building to one that is mostly dynamically externalized or high function externalized. This indicates that a large amount of occupied space is actually fully externalized to the environment. For ECS with their out-the-door curriculum, this ratio best aligns with their educational beliefs.

For daylight performance, the terraced garden iteration actually performed lesser than the two previous iterations. This was likely due to the more intensive structures added on the southern façade, which resulted in less optimal daylight performance. The overall performance was still high, though more formal considerations would need to be taken prior to its implementation. For this exploration however, that level of detail will not be explored further. However, in contrast, the EUI analysis showed that the terraced garden iteration performed better than the shutter façade or dynamic façade, which could be due to the impact of the dynamic structure added to the southern façade that acts as a thermal buffer and storage during winter months. Understandably, the heating load becomes miniscule, with added focus on equipment loads becoming the largest building load. Lastly, the cost analysis indicated that

similar to the dynamic façade, reduced construction cost can actually serve to improve the overall building performance by a slight amount. In the most optimized scenario, $11,082 can be saved while providing 1% payback in energy savings. This would result in improved energy performance in addition to reduced construction costs.

Last of all, periphery social completely transforms the school by pushing the circulation to the perimeter of the building. Periphery Social pushes circulation to the periphery edge of the building while incorporating social spaces and community gathering spaces into the circulation itself. This allows for a richer and engaging circulation that allows for spontaneous interactions, collaboration, and social activities to take place in traditionally "transitory" spaces. Additionally, this can be combined with greenscapes or vegetation to provide added environmental benefits in addition to the social richness that stems from this strategy. In this iteration, the use of the periphery social pushes the central circulation to the perimeter of the building, which hollows out the building center to create a new atrium that can allow natural daylight to penetrate in. This also provides the school flexibility to adjust the building's porosity based on seasonal conditions on all sides given the dynamically externalized double skin. The approach makes the building largely dynamically externalized (at a combined 91.5%) based on seasonal conditions, and offer more natural daylight into the whole building. However this does reduce the amount of high function or circulation externalized spaces, which reduces the amount of diversity and gradients of externalization is provided in the design, as well as can result in the "over cladding" of the double skin. In this iteration operability becomes highly important, influential in the success or failure of externalization (based on occupant behavior), and proposes new challenges in terms of construction cost, material cost, and questions of excess. The newly created atrium space allows for improved daylighting qualities all the way to the first floor, removing large amounts of originally environmentally disconnected spaces, but results in a seemingly less efficient circulation design for the building. Though the strategy does not perfectly fit the case, it does provide important environmental and social benefits that should be further considered, while the design's drawbacks should also be re-evaluated for future design development.

For the natural daylight performance of this iteration, the large additions did not benefit the overall lighting performance of the building. The spatial daylight autonomy decreased to 62.4% (in comparison to previous iterations), and the annual sunlight exposure was still at 21.7%. This indicated that this iteration provided the most natural daylight challenges, meaning the approaches from other iterations provided more successful natural daylight design solutions in comparison to this iteration. Further exploration and simulation would be needed to improve the building performance of this design. This iteration similarly performed well compared to the 2030 baseline, though comparatively less than the shutter façade and terraced garden iterations. This indicated that the approach was not ideal given its (comparatively) poor daylighting performance with no evident improvement in the EUI performance either. Lastly, similar to the previous two iterations, periphery social actually benefitted from improved energy savings with less upfront cost. The construction would save $16,190 with 2% improved energy savings based on the most optimized option found in Cove.tool. This is once again likely due to the thermal storage of the double skin that allows for performative savings that may result in some building

system machinery being too high-tech relative to their overall usage/impact on the total building energy load.

In terms of building performance, each iteration performs at roughly half of the US national median EUI for schools through externalization, which equipment now becoming the main energy load factor in each iteration. Due to the implementation of externalization along with the use of passive strategies, the heating, cooling, and lighting loads are all significantly reduced. This results in the equipment load being the dominant load for each iteration. These iterations are still slightly above the 2030 target of 18.33 kBtu/ft^2/year, but through an iterative design process, these preliminary designs could likely reach the 2030 target. Especially considering that, these four iterations are all preliminary designs to explore the value of externalization; these results highlight the potential of externalized thinking. Additionally natural daylight analysis shows that the daylight quality improves greatly through these designs due to increased connections to the environment, though to varying degrees. Overall, their performance are still quite meaningful.

Conclusion

From the growing impacts of climate change and concerns for building energy loads to the established importance of nature on human health and wellbeing as we become increasingly urbanized to the growing concerns for isolation and social disconnectivity, how we understand 'boundary' and shape our spaces become ever more critical. The conventional approach of internalization was supported and bolstered by the development of technology, but as new concerns arise in the 21st century, it is necessary for architecture to shift from the internalized design approach that have become the 'norm' to a new externalized design approach that reconnect people to the environment and to each other. Especially in the age of pandemic where quarantine, isolation, and social distancing have become commonplace, externalization becomes a crucial design approach that serves to support the necessary connections that are needed while abiding by the many health and social restrictions that define the current lifestyle.

This synthesis establishes foundational research, framework, and design work to encourage and support design professionals in shifting from the current internalized design approach to an externalized approach that allows its occupants to embrace both nature and the community, so that we can create spatial environments that embraces connectivity rather than isolation.

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A Historical View of Addressing the Connectivity of the Green Infrastructure by the Urban Plans

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Abstract
Urban ecology sees today the city nature as a green infrastructure providing ecosystem services to the urban dwellers, contributing to their welfare and a sustainable urban development. However, the concepts included in this view are not as new as it seems. Ecosystem services are just a reiteration of the ecological economy view of nature as a natural capital providing goods and services to the human society. Similarly, although increasing attention has been paid lately to the green infrastructure and its role in addressing challenges faced by the modern society, including the mitigation of climate change effects, it is less known that the concept, that started being used relatively recently, in the '90s, has emerged at the end of the 21st century in the works of the prominent landscape architects and urban planners Frederick Law Olmsted and Ebenezer Howard. They argued in their projects, revolutionary for that time, for the need to combat urban sprawl through a strategic planning of vegetated systems and corridors, known today as "green infrastructure". The designed components of the systems of urban parks and green spaces are similar to those of the "green infrastructure", consisting of nodes (core areas/hubs) and connections. The relationship between nature and human well-being (known today as "ecosystem services") and sustainability was also anticipated by their woks. Most importantly, these early researches demonstrated that the green infrastructure is not optional, but must be strategically devised, holistically planned, and properly managed. This work aims to revisit the old works from a modern perspective.

Keywords: Ecological Infrastructure, Interconnection, Networks, Natural Systems, Landscapes, Strategic Planning, Urban Sprawl, Human Wellbeing

1. Introduction

The name *green infrastructure* entered the usual vocabulary relatively recently, in the 1990s, but the idea of such an infrastructure was born in the 19th century, in the activities of urban planning and landscape architecture. The concept emerged to counteract the fragmentation of habitats and landscapes, because with the expansion of urban areas, green space had become increasingly fragmented, ignoring the benefits it offers, including that of maintaining the city's biodiversity (Zhang *et al.*, 2019).

The concept was also introduced in EU policies, and by 2010 it was already concluded that green infrastructure is important both theoretically and practically. In EU documents, the *green* infrastructure was assimilated as the *ecological* infrastructure, and the definition adopted by the European Commission (2013) was: "*a strategically planned network, made up of natural and semi-natural areas, as well as other environmental elements, which is designed and managed to provide a wide range of ecosystem services*".

Today, the definitions of green infrastructure are numerous and diverse, depending on the authors who approach the concept (Mell, 2010) and the sector and context in which it is applied (Benedict and Mahon, 2002). On the whole, green infrastructure is seen as a specific landscape resource (e.g. a large park), as a component of a larger resource (e.g., a network of green spaces in a city), or as a concept that it incorporates a large number of green spaces and gives them a name (Kleiber *et al*., 2002). However, the ecological aspect of the concept determined the name of *green infrastructure* (Walmsley, 2006).

Reviewing the definitions of green infrastructure in the last 30 years, both officially and in the specialized literature, it is observed that, broadly speaking, they have in common several key words: "network", "interconnection", "benefits", "planning", "management" and expressions such as "natural systems", "interconnected network" or "strategically planned network". The most often mentioned elements as being characteristic for the green infrastructure are: "access", "diversity of scales" to which it applies, "multi-functionality", "natural and human benefits", "biodiversity", "sustainability" and "**connectivity**".

The common idea remains that of **connectivity**, being observed that by creating a network of green infrastructures as wide as possible, more social, economic and environmental benefits can be obtained (Mell, 2010), offered to different social groups. Therefore, although the definitions are numerous, the consensus is that *green infrastructure is an opportunity for social, economic and environmental benefits* (Wright, 2011).

Studies and research have shown that green infrastructure is composed of different natural / reconstituted ecosystems as well as of landscape components. This system contains central areas/centers/*hubs* - which anchor green infrastructure systems, providing origins and destinations for wildlife and for ecological processes that take place here - and *links* - respectively the connections that allow the operation of the system and of the network of green infrastructure (Petrişor *et al*., 2016). In order to work, these above-mentioned elements need to be protected, and this can be done through a **long-term planning** (Benedict and Mahon, 2002). By promoting integrated

land use management, the idea of *green infrastructure* it is closely linked to climate change mitigation, sustainable urban development and social equity, which in turn promote the principles of **sustainable development** (Mell, 2009).

The subject of green infrastructure is important from ecological, social and economic viewpoints and by involving planning activities at territorial level. This research is part of a larger study on the connectivity of green infrastructures and its relation with spatial planning.

2. Method

The article presents several results obtained in different studies, articles and books on the topic of green infrastructure, to identify the first uses of interconnected green infrastructure systems as a method of mitigating urban expansion. For this, the article proposes two case studies.

The first refers to the contribution of *Frederick Law Olmsted*, considered to be the "father of landscape architecture in America", who developed, together with the architect Calvert Vaux, the first *system of interconnected parks* to be implemented in its country. The urban parks that Olmsted designed in 1880 were connected by networks of green spaces that offered citizens opportunities to connect both socially and economically. At that time, it seemed that the focus was not on ecological issues, but rather on social and human ones.

This first case study will show that although terms such as ***green infrastructure*** or ***ecosystem services*** were not used in the 19th century, Olmsted's achievements demonstrate an early understanding of these notions, the components of these designed urban park systems being similar to those belonging to today's green infrastructure.

The second case study refers to another way of using green space to counteract the uncontrolled expansion of the city in nineteenth-century England, also contributing to the birth of current urban planning. Just as Olmsted is representative of America, so Ebenezer Howard is seen in Europe as a revolutionary of his time, proposing the design of polycentric networks of small urban towns connected by a **system of green infrastructure** in an effort to mitigate urban expansion - the "Garden City" theory.

In order to have a complete picture and to reach the more recent period, the article presents at the end the way in which the transition from *green ways* to *green infrastructure* was subsequently made.

3. Case Studies

3.1. Frederick Law Olmsted's parks and alleys systems - the first example of urban planning

In 1870 Frederik Law Olmsted started from the idea that no park, no matter how big or well designed, can offer people the same benefits as the nature, and if it were part of a park system, it would be more complete and even more useful than a single one (Benedict and Mahon, 2002).

Therefore, the urban parks designed by him together with the architect Calvert Vaux were connected by *parkways* that connected the elements of the system.

In the context of the industrialized cities that had begun to develop at that time, these first planned networks had many functions and were not mere refuges for the city's citizens. What is now known as the "Emerald Necklace" (a system of parks interconnected by alleys and waters) was one of the first planned networks having functions and capacities such as accessibility or the flood mitigation (Mell, 2010).

Theodore Eisenman describes the park system designed by Olmsted, citing Witold Rzbcyznski (1999) as "a refined network of parks, alleys, boulevards, and public spaces that represented a degree of refinement in urban planning, previously unknown in the United States."

In Olmsted's view, the central component of the system was a large park, in order to counteract the daily stress of urban life, but there were also elements of secondary importance, such as picnic places or those intended for civic events, such as musical performances, activities for which was considered better to take place in planned places and not to interfere with the landscape.

The elements of this system were linked by alleys ("parkways"), represented by green strips about 200 m wide that connected the parks and playgrounds, creating neighborhood parks and through which it was possible to move from one park to another and through the city. The parkways were separated according to the type of transport, and the directions of travel were separated by rows of trees. The term and the concept of *parkway* have been preserved even today, and refer to a road with trees on the edges and through which commercial traffic is excluded (Beveridge and Rocheleau, 1995).

Olmsted designed the largest park system in the city of Buffalo (Figure 1), which today can be seen as a way to connect green infrastructure, in order to improve the quality of people's lives from a social, economic, mental and physical point of view. He provided compositions of **nuclei** and **connections**, similar to those of today's green infrastructure (Figure 2), in which the nuclei had different shapes and sizes and were represented by parks, reserves or arable land, and the connections were represented by vegetated corridors connecting the nuclei. These corridors could serve several purposes: they were biological conduits for wildlife, they could perform ecosystem processes such as flood management in riparian areas, or they could simply be opportunities for outdoor recreation.

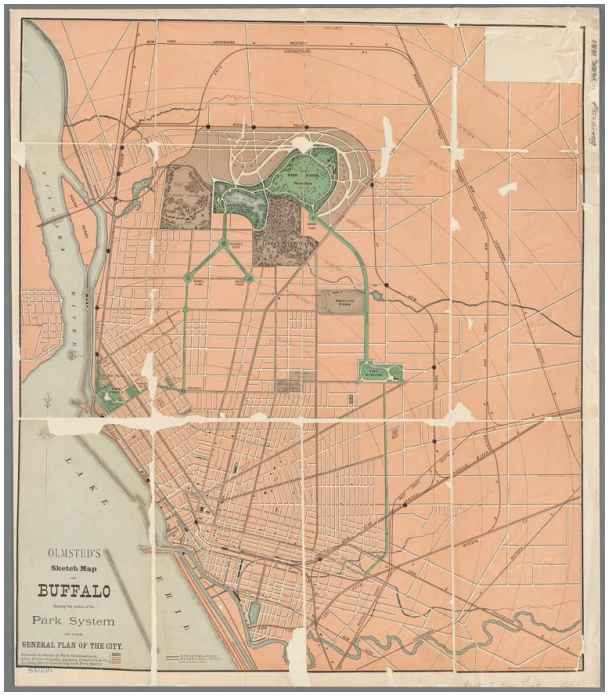


Figure 1: The Buffalo City Park System. Source: https://commons.wikimedia.org/wiki/File:Olmsted_Buffalo_Map.jpg

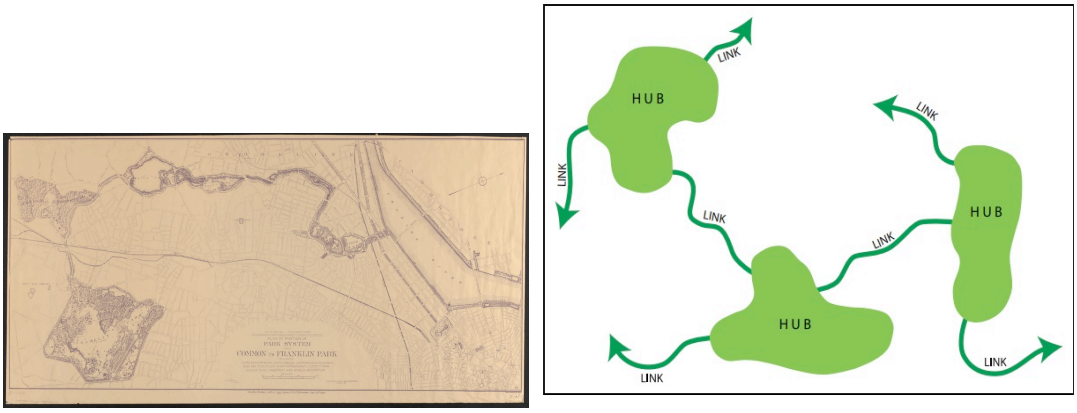


Figure 2: The plan of a park system in 1894 and the representation of the concept of green infrastructure today. Source: https://www.digitalcommonwealth.org/search/commonwealth:ht2503205

The park systems designed by Olmsted are still visited and cared for today. According to the Buffalo Olmsted Parks Conservancy, the Buffalo park system contained (Figure 3): 6 parks (of which the most important was Delaware Park), 7 promenade alleys (connecting individual parks with individual city streets) and 8 squares at the intersections of the alleys with the main crowded streets of the city, consisting of small spaces for flowers, sculptures, fountains or monuments (Figure 4), around which one could get either by walk or by bike or car, so that visitors could enjoy the natural beauties of the city (see also Frederick Law Olmsted – Designing America, https://www.pbs.org/wned/frederick-law-olmsted/learn-more/olmsteds-buffalo-park-system-and-its-stewards/).

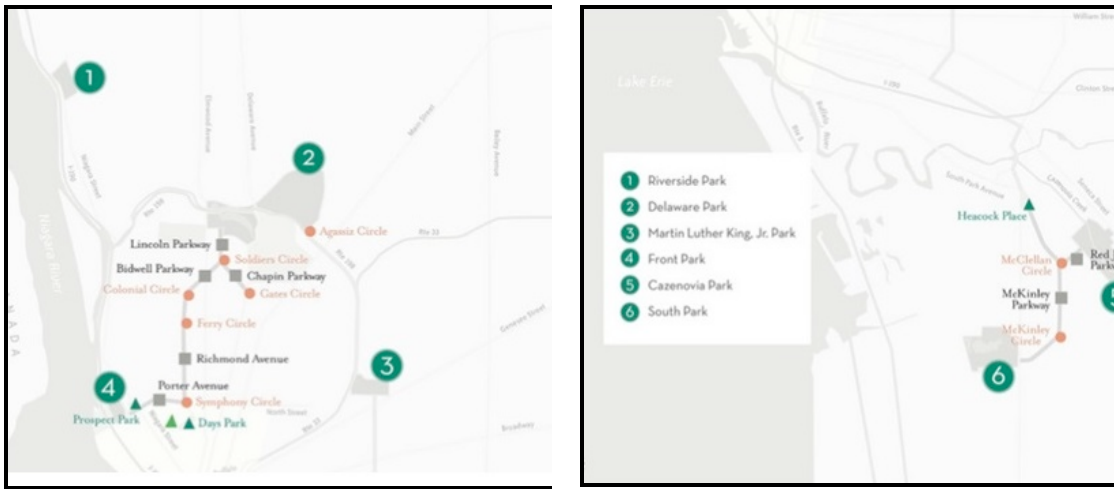


Figure 3: The system of parks and alleys designed by Olmsted in the city of Buffalo. Image source: https://view.publitas.com/bopc/olmstedparkmap/page/4-5)

Figure 4: One of the squares designed by Olmsted (1911) to connect the park's alleys with the main roads of the city. Source: https://kendev.com/history/history-buffalo-beautiful-olmsted-parks/

Olmsted's stated goal was for the visitor to be able to walk from one park to another without leaving the green space and to feel "more in the park than in the city".

It was the largest park system, not only in Buffalo, but also in America, declared in 2015 by *The Guardian* as one of the best park systems in the world (for more details see https://www.theguardian.com/culture/2015/aug/07/10-best-parks-urban-green-spaces-high-line-new-york-hampstead-london-park-guell-barcelona). Olmsted declared in 1876 that the city of Buffalo was "the best planned city in the United States, if not in the world" (Kowsky and Olenick, 2013). Buffalo's park system has been designed to improve the quality of life in the city socially, economically, mentally and physically. Like other parks in the system, Delaware Park, the largest, has been developed and supplemented with other recreational land, and it was named

by the American Planning Association in 2014 "one of America's great places" and remains a popular destination among tourists and locals (Figure 5).

Figure 5: Delaware Park in 1898 and 2011 (Hoyt Lake). Image sources: https://commons.wikimedia.org/wiki/File:Bridge_in_Delaware_Park,_Buffalo,_N.Y_(NYPL_b12647398-69605).tiff and https://commons.wikimedia.org/wiki/File:Delaware_Park_panorama.jpg

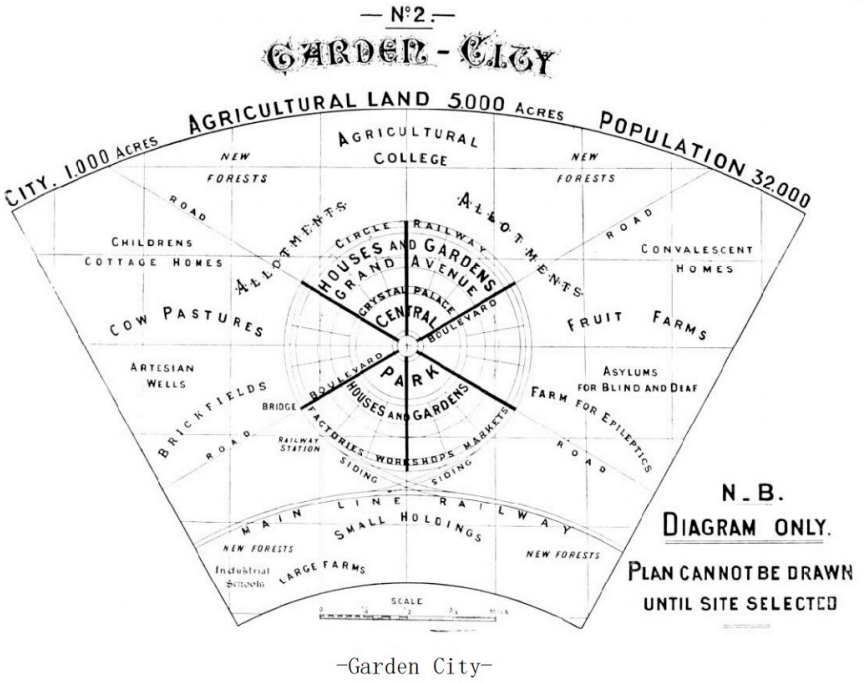
Benedict and Mahon point out that, if at that time the connection of parks was designed for the benefit of people - recreation, walking, cycling, public health, today it is considered that the idea evolved into modern concepts such as *greenways* and *green infrastructure*.

3.2. The green infrastructure systems proposed by Ebenezer Howard as a measure to mitigate the uncontrolled expansion of the city.

In England, Ebenezer Howard continued Olmsted's ideas in 1898. He was also considered radical for his time, proposing the design of polycentric networks of small urban areas, and by creating a system of **green infrastructure**, Howard hoped to mitigate or control urban expansion. His intentions were that each such a city to contain a sustainable transportation system, housing, green infrastructure, to provide affordable jobs and other services. Through this, he encouraged the daily use of green spaces in the immediate vicinity of homes.

Howard's theory at the time - *Garden City Theory* - consisted of planning an ideal concentric city of 2,400 ha and a population of 32,000 made of the urban and rural population that was integrated into the city (Howard, 1946). The city was circular, and in its center was a park (Figure 6). Through the 6 large boulevards 37 m wide that started from the center, the city was divided into 6 sectors.

The theory appeared in the context of the industrial revolution in the second half of the eighteenth century in European countries that led to the intensification of urbanization and generated social and environmental problems. The rapid growth of the urban population, the urban expansion, the growing demand for housing, the pollution of the air and water, the deterioration of the urban environment imposed **the need for an efficient urban planning**, adapted to the reality of that time.



-Garden City-

Figure 6: The Garden City Plan. Image source: https://journals.openedition.org/cve/docannexe/image/3605/img-3.jpg

It should be noted, however, that Howard's idea of a Garden City does not emphasize green space as having a recreational role (as in Olmsted's case), rather, it was conceived as a model in which industry and agriculture could be harmonized or, moreover, in which agriculture is considered a branch of industry.

But how was this utopian city conceived?

From the center to the circumference, the city was crossed by 6 large boulevards that divided the city into 6 equal parts. In the center was a circular space - a **garden** (2.2 ha) surrounded by public buildings. According to this theory, the circular space was surrounded by a large **public park** (the Central Park - 58.7 ha) which contained large recreational spaces with easy access to all residents. Around this park is an archway that opens onto the park, where there is a building - "the Crystal Palace", where people could come especially on bad weather days to shop, and its circular shape being able to bring together the inhabitants of the city.

Passing from the Crystal Palace to the outside of the ring, there is a boulevard (Fifth Avenue) with trees. In front of it are houses built in concentric rings, which lead to various boulevards or roads that converge to the city center. Here can live around 30,000 people from the city itself and another 2,000 from the surrounding agricultural area (with pink in the drawing), in about 5,500 housing units.

Towards the outside of the ring was Grand Avenue, 128 m wide, which forms **a green belt** about 5 km long (and which divided the outer part of the Central Park into 2 belts) (Figure 7). There was another **park** of 46 ha, and the boulevard was occupied by public schools and related play and sports areas, as well as churches.

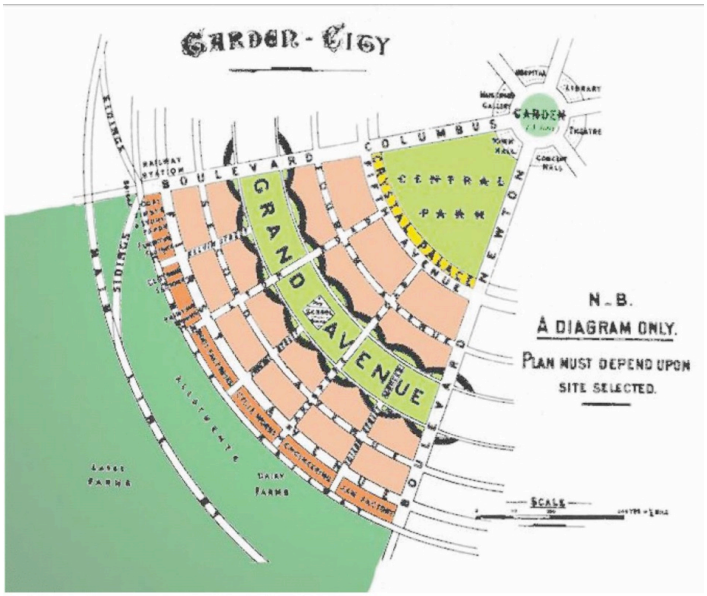
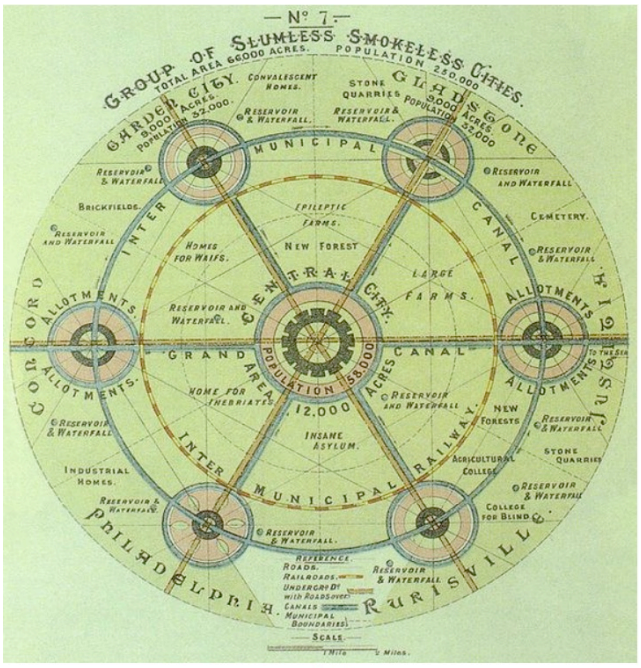


Figure 7: The individual structures of the Garden City. Image source: https://rethinkingfoodpioneervalley.files.wordpress.com/2014/12/ebenezer-howard-garden-city.gif

Finally, on the outer ring of the city (represented in pink in Figure7) were the factories, the markets, towards the railway that surrounded the entire city and which was connected by a railway that passed through the city. This allowed the loading of goods directly, reducing traffic on city roads, all machinery being powered by electricity.

Thus, this garden city would have been ideal for self-development and maintenance, and after reaching a population of 32,000 inhabitants, a similar second would develop in the vicinity, resulting in a cluster of garden cities, as satellites of a central city with 58,000 inhabitants. Cities isolated the green belt and were interconnected (Figure 8).

Of course, the Garden City theory is more a matter of social transformation than a matter of urban planning (Howard, 2013). However, the theory has been adopted by cities around the world and is of great importance for urban planning of green space. Emphasis was placed on the need for green spaces - such as the park and central boulevards - for services, but in particular, the use of green space was proposed to counteract the uncontrolled expansion of the city, which contributed to the birth of current urban planning.



-Social City-

Figure 8: The Social City - a central city surrounded by small satellite towns. Image source: https://journals.openedition.org/cve/docannexe/image/3605/img-1.jpg

4. Discussions

Olmsted was not only one of the leading park designers of the 19th century, but he also predicted the connection between nature and human well-being, which underlies what we know today as ***ecosystem services.*** Contemporary studies of the **psychological benefits** of contact with nature in urban environments underpin Olmsted's intuition a century ago. Although terms such as "ecosystem services" and "green infrastructure" were not part of the 19th-century lexicon, his work attests to an early understanding of these concepts (Eisenman, 2013).

Subsequently, the Millennium Ecosystem Assessment (Reid *et al.*, 2005) identified 4 ecosystem services essential for human well-being: **support services** for soil formation, photosynthesis and the nutrient cycle; **supply services** with food, water, wood, fuel; **regulatory services** in relation to climate, floods, diseases and water quality; and **cultural services**, those that offer recreational, aesthetic and spiritual benefits.

From ecosystem services derive several components of well-being, including health, good social relations, security and freedom of choice and action (Figure 9). Some authors also demonstrate positive links between nature and social cohesion.

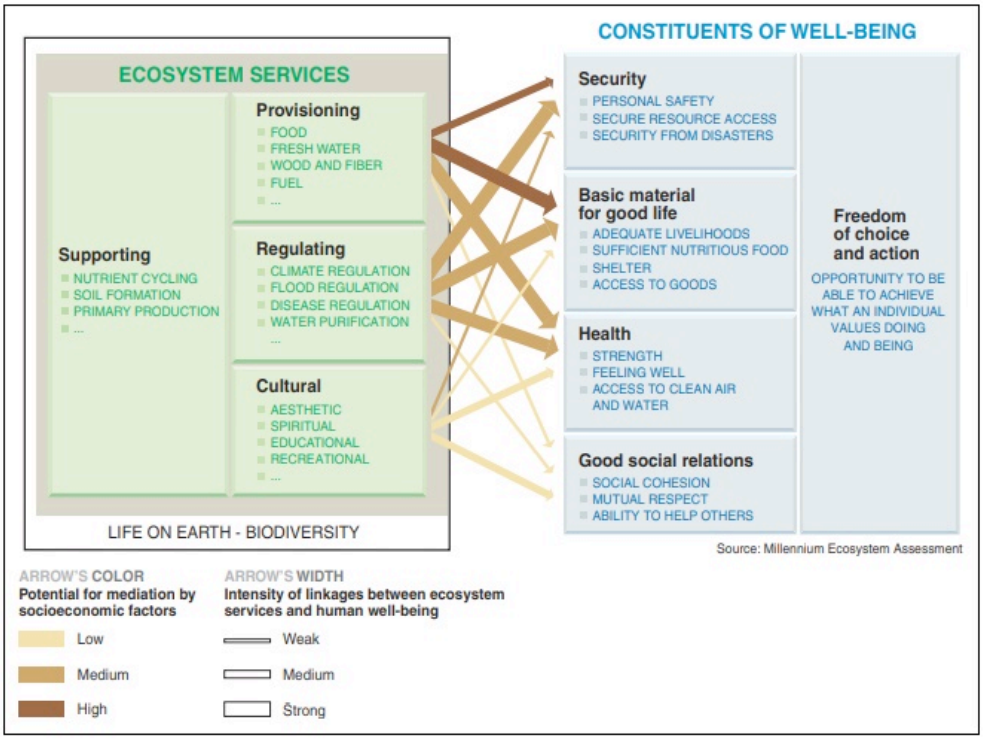


Figure 9: The links between ecosystem services and human well-being, according to The Millennium Ecosystem Assessment. Image source: https://www.millenniumassessment.org/documents/document.429.aspx.pdf

Olmsted intuited that in order to obtain as many benefits as possible on multiple levels, the connectivity of green infrastructures is a necessity. Another anticipatory thinking that Olmsted refers to is what is called **sustainable development** today.

He motivated the planning of his first system of parks and alleys by the need to meet the future urban development, and not just to look at the immediate satisfaction of the population. The idea is similar to today's definition of the concept of sustainable development, which states that it must meet the needs of the present without compromising the capacity of future generations to use their own needs in the future. He was a future-oriented spirit and had a systemic thinking about urban planning, believing in the development of cities.

He also stressed in his speeches that environmental protection should be a fundamental responsibility of democratic governance, which again reflects contemporary ideas on **social equity and sustainability**, both of which are particularly relevant today in the discourse of **urban ecology**.

And last but not least, what draws attention to the work of Olmsted, and later Howard, is the anticipatory thinking about the expansion of cities and the need for planning to counteract this growth in the future, in the idea that the city would be better served by an interconnected system of green spaces (parks) than by a single large park.

Following the achievements of Olmsted and his successors, including Howard, the "Greenways" were created after the 1950s, in order to conserve the ecological resources of landscapes. Although the emphasis was initially on the role of conserving riparian and ecological corridors, over time the emphasis has been on recreational and

leisure functions. **Greenways have influenced the planning and implementation of green infrastructure.**

Definitions of greenways have been proposed since 1987, seen as *networks of green and nature corridors* (Fabos, 1995). As greenways have evolved, the notion of *road* becomes *corridor*, which makes green networks seen as corridors of different widths that are connected together in a network similar to the road or rail network, the only difference being pre-existence of greenway corridors.

The greenway movement originated in the United States in the ’50s, when the term *greenway* first appeared to describe recreational trails (for pedestrians and cyclists), designed to promote a healthy lifestyle and an environmentally friendly, non-motorized transportation, especially in urban areas.

In Western Europe, this concept became popular only in the '80s and' 90s. Already in EU countries, greenways referred to **green corridors** dedicated to tourism, recreation and non-motorized transport. These routes have been designed along roads, railway corridors, natural corridors or unused roads, as being independent of motorized routes. Their motivation was "promoting an active and healthy lifestyle, conserving nature, reducing pollution from motorized transport and creating safe access to school or work” (Benedict and Mahon, 2002).

In 2005, Nicholls and Crompton (2005) stated that establishing greenways is essential in terms of land use planning. In Europe, some cities (Amsterdam, Helsinki, and Copenhagen) have been designed by creating urban fabric in conjunction with accessible and quality green spaces, with designers providing urban areas with large green spaces. Thus, each city used a network of **green infrastructure** to promote ideas that were previously found in the planning of greenways (such as social inclusion, recreation, economic regeneration).

Currently, the issue of greenways has started to be discussed with the development of green infrastructure, which was different in Europe from the US, evolving according to the existing planning problems in each part of the world. For example, in the US the creation of green infrastructure has been influenced by the creation of the Urban Green Agenda and the need to create a green space integrated into high-density landscapes and emphasizes the **ecological** benefits, not the social and economic ones. Americans Benedict and McMahon were the first to say that **green infrastructure restores the ecological role that greenways originally had**.

5. Conclusions

Looking at each part of a park as part of a corresponding urban plan, Olmsted demonstrated the need to combat modern urban sprawl through regional planning. By replicating the morphology, hydrology and plant composition of certain ecosystems, his work from the end of the nineteenth century laid the early foundations of what we understand today by **green infrastructure.**

Olmsted's greatest contributions were to predict the continuous expansion of cities, the need for strategic planning to deal with it, and the need for a physical system of

vegetated spaces and corridors - *green infrastructure* - essential in shaping urban expansion in time and space.

Howard also laid the foundations for revolutionary concepts of urban planning (decentralization, zoning), and in terms of green infrastructure, he laid the foundations for the concept of integrating nature into the urban fabric, including in the form of green belts.

Both Frederick Law Olmsted and Ebenezer Howard predicted that vegetated space and corridor systems could impede the continued expansion of cities. Their ideas contributed to the emergence of strategic planning, and their concepts served as antecedents in the birth of urban planning at the beginning of the 19th century.

As proof that the two had the right thinking, today it is considered that "green infrastructure is a simple but at the same time extremely complex approach to landscape planning" (Mell, 2016).

Green infrastructure is associated with ecological functions and the idea that its fundamental role is to connect people in green spaces has been preserved. We can conclude in this context that **green infrastructures must be designed as multi-functional spaces that can offer human and ecological benefits**.

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Environmental and Social Engagement Best Practice to Face Pandemic Circumstance: A Sharing from Vale Indonesia, Sorowako Site

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Abstract
The COVID-19 pandemic in 2020 has broken the normal bonds of human interaction, whether in the personal sphere or in the industrial sphere, regardless of where a person happens to live. Several industries which play important roles in fulfilling global demands, including the nickel mining and smelting industry, still need to resume operations in full regardless of the global disruption caused by the coronavirus outbreak. They also have to maintain an environmentally-friendly practice while stepping up social engagement to support community who has been adversely impacted by the pandemic. This paper focuses on how Vale Indonesia is still conducting its business operations to maintain its daily business while adhering to the precautionary measures on its surrounding communities. Vale has actually coined several innovative programs to improve environmental concern, consisting utilization of waste materials to reduce demands for single-use ones. On the other hand, the company has also focused on conducting social engagement and community support activities, especially by providing life support assistances and programs which can boost the communities to be more productive and improve their capacities to be resilient amid the devastating impact of the pandemic. Vale has calculated that Sorowako sites will be able to maintain their environmental management by contributing to energy efficiency 12,626.00 GJ, emission reduction 17 tons of PM, waste utilization (hazardous 1,994,402 tons and non-hazardous – 20,000 tons), waste efficiency 586,087,488 m3, wastewater effectiveness 19.94 tons of TSS, reclamation activity of 149 plants species and empowered more than 5,000 communities over the course of a year.

Keywords: Environmental Management, Social Management, COVID-19 Pandemic, Metal Mining Industry

Introduction

Most industrial activities will likely still focus on resuming its normal operations, although on some circumstances they also have to deal simultaneously with some kinds of an emergency situation. These emergency situations can be natural or human-made. Some natural emergency or disasters can also undoubtedly be exacerbated by humans. The COVID-19 pandemic is an excellent example of this whereby a virus or a disease spreads through human activities and interactions. The pandemic started at the beginning of 2020.

PT Vale Indonesia's operational site in Sorowako, a remote area in South Sulawesi, Indonesia (see Figure 1), has also been impacted by this situation since the pandemic has required the company to come up with some support and special operational conditions to sustain its entire business process. As one of its emergency actions, the industry has been provided integrated system to maintain its operational condition and surrounding communities. The operation focuses on business lines and their impacts to the surrounding communities, especially in terms of environmental and social impacts. Furthermore, the COVID-19 situation also requires the company to improve on its health and safety concerns, both for its employees and local communities.

Figure 1: Vale Indonesia – Site of Sorowako

The paper presents the company's industrial efforts to balance environmental management and social engagement with its operations during the pandemic. The company has come up with several innovative programs to manage these domains and it has implemented these programs well up to this moment. Some of the programs have been motivated by dramatic restrictions on human interactions and mobility due to the COVID-19 pandemic, thus serving as an impetus for the company to replace single-use, newly-manufactured materials with recycled ones to reduce distribution and logistics activities. The company also innovates with its online monitoring systems to minimize human interaction in the field while maintaining activity trends. The community empowerment effort now concentrates on its activities in skill enhancement programs for local communities in Sorowako, while providing life support for surrounding provinces.

Overview of Vale Indonesia Site Sorowako and Its Support to Covid-19

Vale Indonesia, a nickel mining and smelting industry, operates under Vale Global, one of leading base metal corporations in the world. It has several operational areas in Sulawesi Island; one of the company's sites that has been operating for more than 50

years is situated in Sorowako District, a remote area in South Sulawesi province, Indonesia. The area of operations (see Figure 2.) is surrounded by three provinces, namely South Sulawesi, Central Sulawesi, and South-East Sulawesi. This position delivered the industry to enhance community empowerment endeavors for provinces impacted by its operations. This also covers the company's COVID-19 countermeasures and emergency support, as the pandemic is still going on at the time this paper was written.

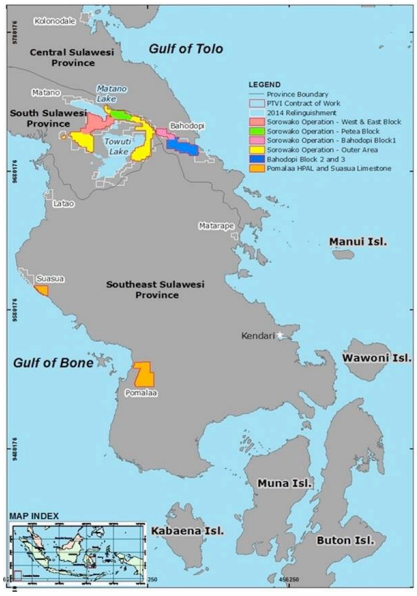

Figure 2: Provinces Impacted by Vale Indonesia's Operations

The company's COVID-19 community support program comprises distributing personal protection equipment, providing rapid tests and conducting educational programs to educate the public on the pandemic and how to prevent further virus infections in the community, distributing meals and setting up emergency shelters where people can gather. You can see a summary of these countermeasure activities in Figure 3.

Figure 3: Support Activities during COVID-19

To date, the industry, along with its stakeholders, have supported local communities via these activities across the three provinces mentioned above, as can be seen in detail in table 1.

Table 1: Cumulative Community Support Comprised within the Company's COVID-19 Countermeasures and Prevention Acts

No	Area	Quantity	Unit price	Plan quantity	Actual Quantity Per 11/9
1	East Luwu	Rapid Test	6.30	10,000	-
	East Luwu	Alcohol Swab	0.04	10,000	-
	East Luwu	Lancet	0.03	10,000	-
2	South Sulawesi	Rapid Test	6.30	30,000	40,000
	South Sulawesi	Alcohol Swab	0.04	30,000	-
	South Sulawesi	Lancet	0.03	30,000	-
3	Morowali	Rapid Test	6.30	10,000	3,500
	Morowali	Alcohol Swab	0.04	10,000	-
	Morowali	Lancet	0.03	10,000	-
4	Central Sulawesi	Rapid Test	6.30	20,000	26,500
	Central Sulawesi	Alcohol Swab	0.04	20,000	-
	Central Sulawesi	Lancet	0.03	20,000	-
5	Kolaka	Rapid Test	6.30	10,000	10,000
	Kolaka	Alcohol Swab	0.04	10,000	-
	Kolaka	Lancet	0.03	10,000	-
6	South East Sulawesi	Rapid Test	6.30	20,000	20,000
	South East Sulawesi	Alcohol Swab	0.04	20,000	-
	South East Sulawesi	Lancet	0.03	20,000	-
7	North Luwu	Rapid Test	6.30	5,000	5,000
	North Luwu	Alcohol Swab	0.04	5,000	5,000
	North Luwu	Lancet	0.03	5,000	5,000
8	North Kolaka	Rapid Test	6.30	10,000	10,000
	North Kolaka	Alcohol Swab	0.04	10,000	-
	North Kolaka	Lancet	0.03	10,000	-
9	Palopo	Rapid Test	6.30	5,000	5,000
	Palopo	Alcohol Swab	0.04	5,000	5,000
	Palopo	Lancet	0.03	5,000	5,000
10	North Toraja	Rapid Test	6.30	**5,000**	**5,000**
	North Toraja	Alcohol Swab	0.04	5,000	3,000
	North Toraja	Lancet	0.03	5,000	3,000
11	Toraja	Rapid Test	6.30	**5,000**	**5,000**
	Toraja	Alcohol Swab	0.04	5,000	3,000
	Toraja	Lancet	0.03	5,000	3,000

(As per Mid-Sept 2020)

We all want that the industries and communities across the globe impacted by the unprecedented pandemic to recover to a better situation soon. It is therefore important for everybody to maintain his or her health and safety situations while also taking care of the environment.

Materials and Methods

This paper discusses some innovations in environmental management by utilizing and optimizing waste instead of utilizing single-use, newly-manufactured materials. Social empowerment for the impacted community is also taking into account as part of their capacity building and preparation for economic improvement after the pandemic. A schema on waste utilization is depicted in Figure 4.

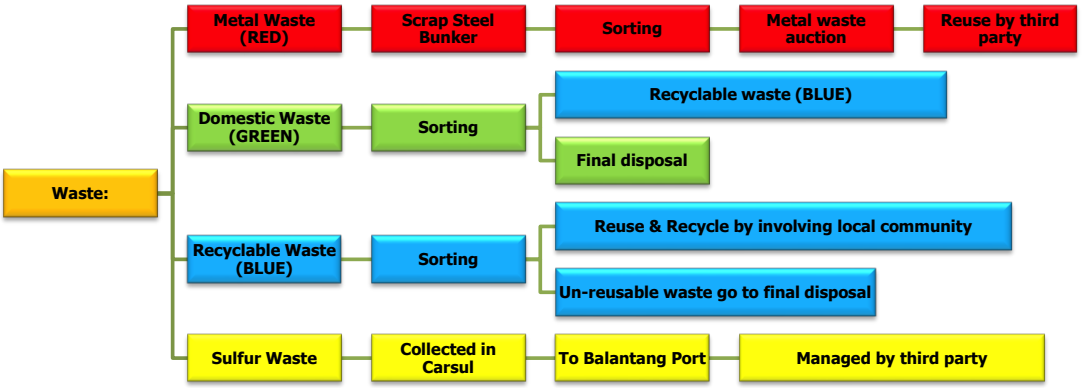

Figure 4: Schema on Waste Utilization in Vale Indonesia

This paper also mentions an Android-based online monitoring system to make monitoring easier while minimizing human mobilization to prevent the virus spreading all the same. The system uses database optimization, with IT-based materials and software installed in computers or personal devices.

On the community empowerment aspect, we recycle waste into organic fish feed. To accomplish this, we need a fishpond, compost fertilizer and local micro-organisms. We use a typical fishpond while testing the compost fertilizers and local micro-organisms using organic materials. We will explain each innovation in our highlighted programs below:

Energy Efficiency: Self-Machining of Electric Boiler Spare-parts

Electric boilers can create high-voltage steam, worth 11 kilovolt (kV). The HVJ electrode steam boiler produces steam using a short process whereby before turning into steam, the boiler will heat the water beneath it before pumping the steam directly to the electrodes which terminals have been attached to high-voltage electricity. About 97 percent of the steam will be formed between the nozzles and electrodes while the remaining ones will fall beneath the boiler before once again creating steam between the electrodes and counter-electrodes. To maintain steam pressure constant, the water pump circulation has been designed to operate and rotate using the variable-frequency drive control according to the steam pressure condition and the burden applied on the boiler on that moment. The construction process of the electric boiler can be seen in Figure 5.

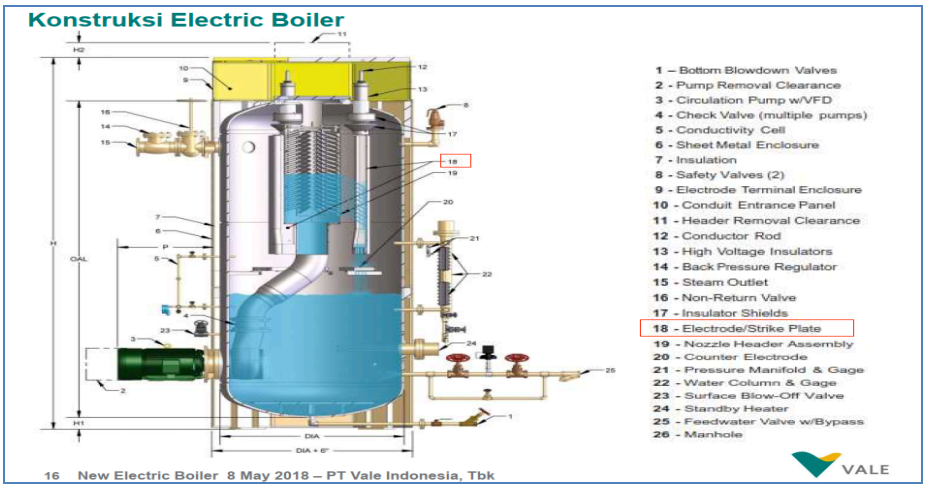

Figure 5: The Construction of the PTVI Electric Boiler

Practically, we will always have to change the spare parts of the electric boiler and yet oftentimes we face an obstacle in procuring the machineries required. This is because the electric boiler is available only in overseas countries, while the procurement process usually takes quite a long time. Therefore, to optimize the operational process without having to shut down some operations while waiting for the boilers to be shipped from overseas, we need to innovate by manufacturing the necessary spare parts, including electrodes or strike plates (see Figure 6), by ourselves.

Figure 6: Strike Plate Part No. 17

Through our designs and fabrications, we need to optimize our machineries while saving time and cost. The company will use the materials available internally or can be procured domestically, while making use of mild steel plates or carbon steel. These materials have a lifetime of six months; original spare parts, meanwhile, will only last for 10 months max. In terms of costs, the optimization could save up to 90 percent material substitution costs. Therefore, the company can still maintain the electric boiler's maximum operational efficiency.

Emission Reduction: Bag House Improvement of Electric Furnace #4

One of the emission controllers in our electric furnace is the bag house, which main function is to control particulates. In its operational activities, however, Bag House often faces some obstacles in terms of leakage capacity, thereby requires some upgrade. Some improvements or upgrades we have conducted on the Bag House include: increasing the surface width of the bag house filter from 4.24 meters to 5.5 meters. In addition to that, we also add more chalk on the filter bag, while conducting routine tests using the vicolyte technology applied on all the bag houses across all operational areas. The Bag House activities can be seen in Figure 7.

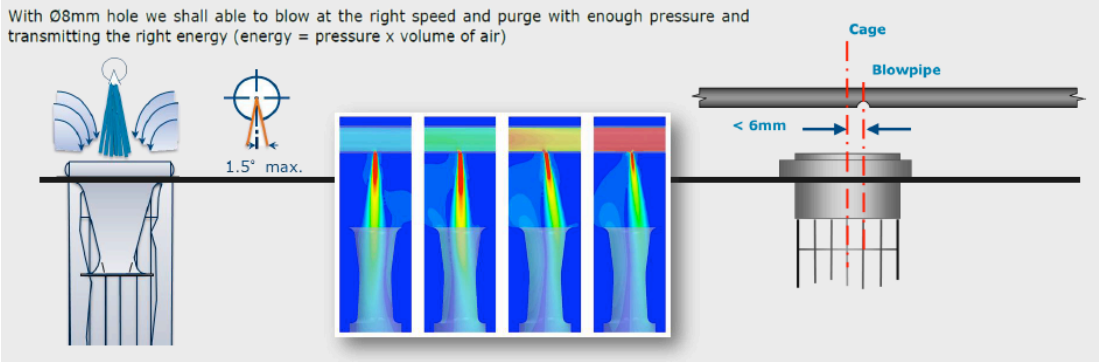

Figure 7: Illustration of Bag House Improvement

The program will be effectively launched in 2020; we expect that it will increase the conventional emission-reduction efforts – in this case, to bring down our particulate emission from 90-120 milligrams per cubic meter to 60-90 milligrams per cubic meter.

Hazardous Waste Management: Utilization of Green Aggregate from Slag Waste

Slag is a non-metal solid waste of furnace metal melting process while also being an aggregate of oxide in a melted form and is separate from the liquid metal form in the melting process. Slag has ***heavy physical characteristics,*** thus is highly potential to be used to sustain a heavy load, making it useful for processes like road construction.

Our activities using slag to construct additional mining roads in PT Vale can be seen in Figure 8.

Figure 8: The Use of Slag to Construct Mining Roads

PT Vale produces slag which, among others, can be used to construct mining roads. The slag is also used as a green aggregate which we call Ecoterako Vale. In total, the program can use up to 1,994,402 tons of slags per annum, with waste utilization rate on average accounting to 90-100 percent.

Solid Waste Management: Utilization of Chipping Materials from Waste Reject Dryer

Area Process Plant creates diverse types of waste, including the Reject Dryer waste. For every 100 metric ton of SSP product processed in the Dryer Process Plant, an average of 15 metric ton of reject dryer waste cannot go into further processing (called the Kiln Processing). We try to make use of the unused waste by recycling it as a substitute for quarry blasting materials in the upper foundation layer in logistical roads. In order for us to use the reject dryer materials as LPA materials, we have to crush the reject dryer to mold them into a maximum size of 28 millimeters, according to the flowchart below. We use the materials for the road upon subjecting them into a series of tests – be it laboratory test or fieldwork test to really gauge the standard quality of the roads made with them, using the process which can be seen in Figure 9.

Figure 9: Flowchart of the Utilization of Chipping Stones from Waste Reject Dryer Facility to Construct Road Base

The area in which we construct a new road utilizes new materials constructed using the reject dryer materials mentioned above. Our old roads, meanwhile, have been recycled using road stabilizers. We utilize these materials in our logistics road areas for overlaying purposes requiring new materials, plant site areas, yard areas such as the Delaney tyre shop, Delaney tyre storage and the community support area, etc.

Figure 10: Application and Utilization (Left: Before the Program; Right: After the Program)

The program can also replace 20,000 tons of broken stones from the blasting process per annum. Besides that, the innovation also reduces risks associated with workers' exposure to the explosion process, thereby increasing their work health and safety quality by reducing the intensity of explosion activities.

Water Efficiency: Larona Canal-Lining

This is a linear neomembrane installation which covers over the coarse canal surface. The program makes the canal surface smoother, thus accelerating water flow, resulting in higher electricity produced by hydro power plant with the same water discharge volume. The coarse canal surface slows water velocity down, while leakages at the canal's walls and bottom have weakened the canal ground integrity, which could lead to a canal rupture, while increasing the seismic design from 0.2 gram to 0.4 gram in accordance to the latest standard. Documentation on the construction process after the lining installation can be seen in Figure 11.

Figure 11: Lining Installation in the Larona Canal (Left: The Coarse Canal Surface, Center: After Geomembrane Installation, Right: The Canal's Condition After Being Watered)

During the effective implementation of the program, the company is able to create 586,087,488 cubic meter of water efficiency. The comparison of electric power (in Megawatts) produced before and after the program can be seen in Figure 12.

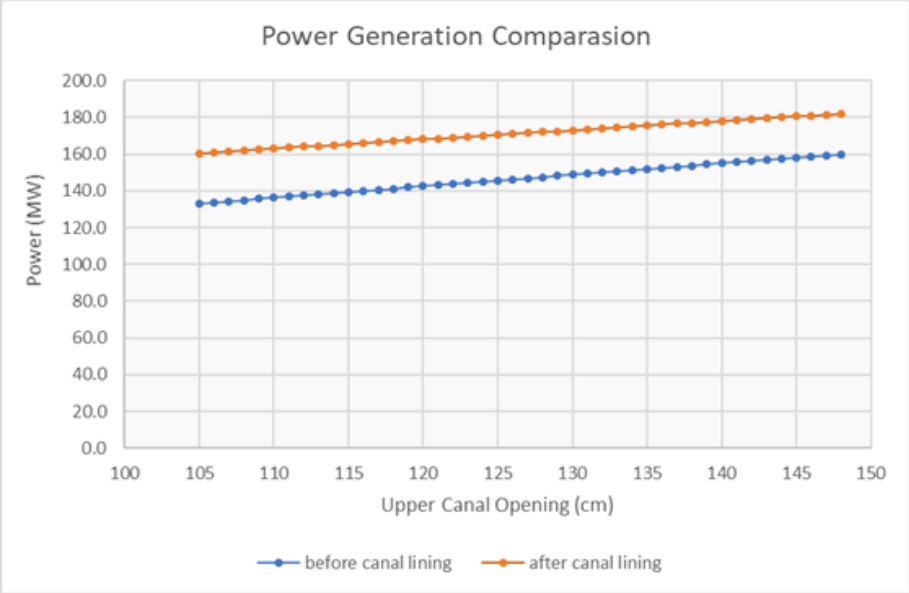

Figure 12: Comparison of Electric Power in Canal

The company implements the program only in the seven-kilometer-long Larona canal starting from the Batu Besi dam straight to the headpond. The canal supplies water from Towuti to the Larona generator.

Wastewater Management: Re-construction of Lamella Gravity Settler

The Lamella Gravity Settler, as have been mentioned in our previous publications, is a wastewater processing unit seeking to reduce suspended solid materials. In PT Vale, LGS is one of the wastewater innovations aiding the mining activities of minerals like nickels. Generally, nickel mines use settling ponds to reduce their suspended solid materials. The pond, however, requires a bigger area width, while in LGS, the width can be reduced by 90 percent.

In the previous LGS construction activities, the company has built an interconnected slurry processing unit, but upon constant effectiveness monitoring which has been done for more than six operational months, the company has discovered that the unit does not effectively reduce the suspended solid materials. Therefore, it requires the slurry solidification process to be reconstructed through a major shutdown by mud removal in the mixing and blade areas, as well as adding more screens in the LGS inlets in the mixing area. There are at least two concerns regarding this process: slurry pump performance which has often been obstructed by tree branches in the inlet flow (causing lots of downtime) as well as the slurry pump performance which could remove mud from the LGS.

The effectiveness of slurry processing in the LGS mentioned previously can be seen in Figure 13.

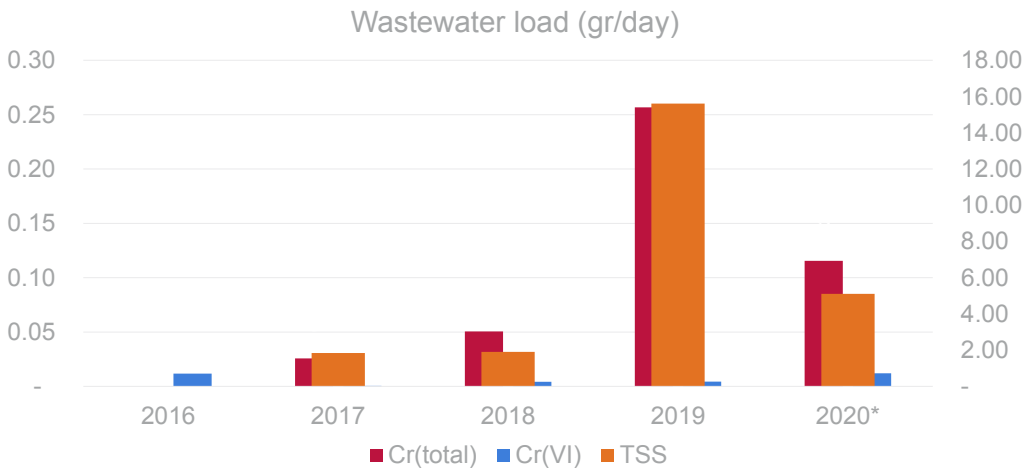

Figure 13: Comparison of LGS Slurry Effectiveness

The picture shows that the program can bring down suspended solid materials thereby also bringing down pollution burden by 19.94 tons per annum.

Biodiversity Conservation: Nursery Information System: Android-Based

PT Vale is developing an Android-based virtual monitoring system to support its nursery activities, which is known as the Vale Indonesia Nursery Information System. The application seeks to address difficulties in recording data on a real-time basis during the monitoring process since the recording is still conducted manually and oftentimes not well-documented. The innovation makes direct monitoring easier; the direct data input on the application has also brought incidences of human error down, and bringing greater impact especially on the management of data production in the Nursery Area under a single database system.

The NISVI application interface can be seen in Figure 14.

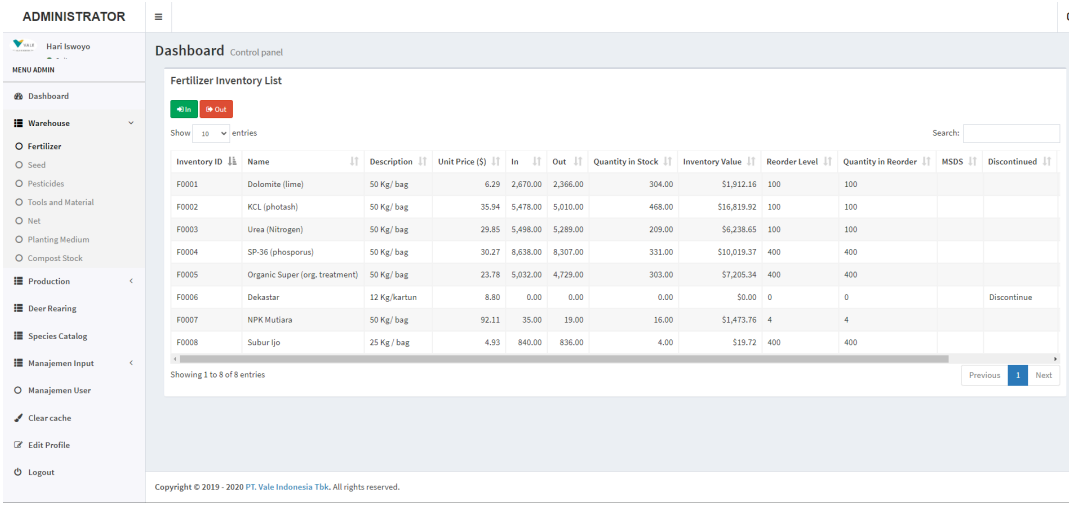

Figure 14: The NISVI Application Interface

Previously, the monitoring data is scattered across several Microsoft Excel files, increasing the likelihood of data duplication as well as creating difficulties in the reporting process. The Android-based application can just be installed in smartphones

and directly synchronized with the company database. As a result of this innovative development, we have come to know that there are at least 149 types of plants which we can cultivate in PT Vale's nursery area, to be later used for reclamation. Currently, the application is undergoing an integrated testing process with an automated nursery watering system, which will be explained in a different publication.

Community Shared Value and Development: Organic Fish Feed

PT Vale also initiates an organic fisheries program to support its beneficiary community so its members can fulfill their daily intake needs of nutritious fishes and enhance their economic income. In the fisheries breeding process, operators allocate the biggest chunk of cost to procure feed, which can constitute 60 to 70 percent of the total production cost. This oftentimes burden the fishermen to a point that it has actually motivated them to manufacture their own feed using high-quality yet affordable organic probiotic technology.

PT Vale has helped its beneficiaries from the fisheries sector to manufacture their own fish feed, whether manufacturing the feed directly in their pond or making vegetable-based fish feed made of materials are already available in nature. You can look at the process in Figure 15.

Figure 15: Manufacturing Organic Fish Feed

For our independent fish feed manufacturing process, farmers have to prepare organic materials available around their breeding area, before turning the materials into compost or organic microorganism. We have to manufacture the feed before we start breeding the fishes inside the pond, because the feed has to be scattered at the bottom of the fishpond when the pond is dry. Meanwhile, the company uses several plants such as water hyacinth, watercress, sweet potatoes, taro and papaya leaves, indigopera, Azzola, etc. to manufacture vegetable-based feed.

Both types of organic feed are beneficial for fish breeders as they can just make use of natural resources to improve their breeding quality. In terms of cost-benefit, the

program could reduce operational production costs by approximately more than 100% per annum, and is capable of boosting fish feed productivity to 12 tons per annum.

Conclusions and Recommendations

We conclude that as a whole, our mining and nickel processing operational activities need to carry on properly even as we are facing a pandemic. Therefore, we need to pay extra attention to the work health, hygiene and safety aspects in our operational area and people who live in its vicinity. The company's essential role can be seen in two aspects: internal affairs, comprising energy and environment management as well as external affairs, comprising community empowerment. Yet, speaking specifically of COVID-19 prevention and mitigation, the company considers the protection of each entity in its internal operational area as well as the larger community in the external environment of its operational area using as many means as possible as a calling. Our model programs and innovations turn out to bring about the following benefits:

1. Energy efficiency worth 12,626.00 GJ per annum
2. Slag waste recycling worth 1,994,402 tons per annum
3. Chipping waste recycling worth 20,000 tons per annum
4. Bringing down dust emission by 17 tons per annum
5. Creating water use efficiency by 586,087,488 cubic meter per annum
6. Reducing waste water pollution burden by 19.94 tons per annum
7. Boosting reclamation monitoring effectiveness by 149 species types.
8. Boosting community economic activities by more than 100% per annum.

We would also like to recommend monitoring energy and environment management regularly; hopefully this management can be done smoothly and more effectively in the future by taking into account several potential disasters which could hobble the area.

Acknowledgements

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Health Risk Assessment of Heavy-Metal Containing Soil Near Some Auto Service Centers of Ulaanbaatar, Mongolia

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Abstract
In this study, assess contamination levels in soil and perform a health risk assessment in the vicinity of some auto service centers in the Ger area of Ulaanbaatar in Mongolia. Thirteen soil samples were collected from an auto services area and analyzed for the concentrations toxic elements such as Cr, Cu, Pb, and Zn, by Atomic Absorption Spectrometry (AAS). The contamination levels were evaluated using the geoaccumulation index. Results of statistical analysis indicated that the average concentration of heavy metals Cu and Pb in the samples exceeded the limits prescribed by the soil standard of Mongolia, with exceeding multiples of Cu (1.82) and Pb (2.48), while those of Cr and Zn were less than prescribed. A total of 12 samples was appearing to be in the range of the uncontaminated to heavily contaminated, with Igeo values less than 3.6 for all the heavy metals except Sample 2. The maximum index of bioaccumulation of soil in the study area was as high as 5.9, indicating the extremely contaminated by anthropogenic. Health risk assessment was performed using the US Environmental Protection Agency (USEPA). Health risk assessment determined that total HI for adults was no exceed than 1, however, for children was estimated exceed than 1. Moreover, the research area overall showed an acceptable range for carcinogenic risks, with the main contributor to the risk being Pb. It was found that 90% of the soil samples did not pose significant health risks in terms of carcinogenic risk, and 10% posed acceptable carcinogenic risks.

Keywords: Auto Service, Heavy Metal of Soil, Health Risk Assessment

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Introduction

Heavy metals can affect the environment which dangerous for human health, the life of animals, and the quality of the atmosphere for a long time (Kasassi, A., et al 2008). An example is the heavy metal lead (Pb) which is a non-essential element to the human body, the excessive intake of which can damage the nervous, skeletal, circulatory, enzymatic, endocrine, and immune systems of those exposed to it (Zhang, X.,et al 2012). Moreover, chronic exposure to Cd can cause adverse effects such as lung cancer, pulmonary adenocarcinomas, prostatic proliferative lesions, bone fracture, kidney dysfunction, and hypertension, while the chronic effects of As can consist of dermal lesions, peripheral neuropathy, skin cancer, and peripheral vascular decease (Żukowska, J.et al 2008). Due to their potential toxic, persistent and irreversible characteristics, heavy metals such as Cadmium (Cd), Chromium (Cr), Arsenic (As), Mercury (Hg), Lead (Pb), Copper (Cu), Zinc (Zn) and Nickel (Ni) have been listed for priority control pollution by the United States Environmental Protection Agency (USEPA) and have been the subject of increasing attention in many part of the world (Abrahams, P.W. et al 2002, Rodrigues, S.M.,et al 1969)

As a result of reforms in the economic and social sectors of Mongolia, the number of vehicles in Ulaanbaatar has increased rapidly in the last two decades. In order to meet with customers' demands, second hand automobiles from Japan and Korea are dominant in Mongolia's auto market. This situation has resulted in an increasing number of auto repair and maintenance service centers. Ulaanbaatar city has 910 auto services centers consisting of 438 auto repair centers, 174 welding and wheel repair service centers, 151 car wash centers, and 54 lubricant-selling points and spare part businesses. There are two types of auto services in Ulaanbaatar city and these consist of public (20 percent) and private (80 percent) centers (National Statistics Office of Mongolia; 2018). The private auto repair services have not been granted licenses for their businesses. They do not have a workplace provided by the appropriate authorities and do not have proper equipment or the facilities for running this type of business.

Sources and literature show that the previous researches mainly emphasized on the air pollution caused by vehicle emission and fuel releasing impacts (Byambaa, B., 2019, Guttikunda, S.K., et al 2013, Bayasgalan, B. et al 2017. Environmental influences of auto repair service have not been studied yet, therefore a measurement of toxic substances and pollution intensity is considered as a priority of this study. The main purpose of this study was first, to assess the concentration of heavy metals in surface soil samples near some auto repair centers of Ulaanbaatar city, Mongolia. The second purpose was to conduct a health risk assessment, based on the concentration of heavy metals, to evaluate possible health risks to adults and children. Third, make proposals and recommendations to decrease the pollution rate.

Material and Methods

Study area. Soil, air, and water contamination occurred due to the population density, harsh climate, and geographical location of capital city of Mongolia. The capital city of Mongolia is located in the arid steppe zone of Central Asia, surrounded by mountains and located in a river valley, which contributes to the accumulation of pollutants in the city's air, water and soil. Ulaanbaatar is located in the southwestern

part of the Khentii Range, in the mountain forest-steppe and dry steppe zone, in the northern part of the Tuul River valley, Chingeltei (1949.7 meters above sea level), in the south Bogd, and in the west Songino Khairkhan (1652.3 meters above sea level), to the east, surrounded by the Bayanzurkh (1845.5 m above sea level.) mountains, extending from east to west. Geomorphologically, it is divided into low and high floodplains. The low floodplain covers an area of 100-500 m north of the riverbed, and the high floodplain is about 0.51.0 m high.

Sample collection. Thirteen soil samples were collected from the soil in the vicinity of auto service centers in ditricts of Bayanzurkh, Chingeltei, Songinokhairkhan and Khan-Uul Ulaanbaatar city in August 2010. (Fig. 1). Those samples were the top 10 cm of soil and the surface soil samples were used to randomly sampling method and to collect using stainless steel scoops, then placed in polyethylene bags and labelled. Non-soil particles such as stones, wooden pieces, and rocks were removed from the soil. These 13 samples were prepared for measurement by acid digestion of sediments, sludge, and soils 3050 B method at the Soil Laboratory of Geographical Institute of Mongolian Scientific Academy. Their toxic substances (Cr, Cu, Pb, Zn) were identified by the Atomic Absorption Spectrometry or the device of VGP210. Results were compared with Mongolia National Standards (MNS5025:2010) [10].

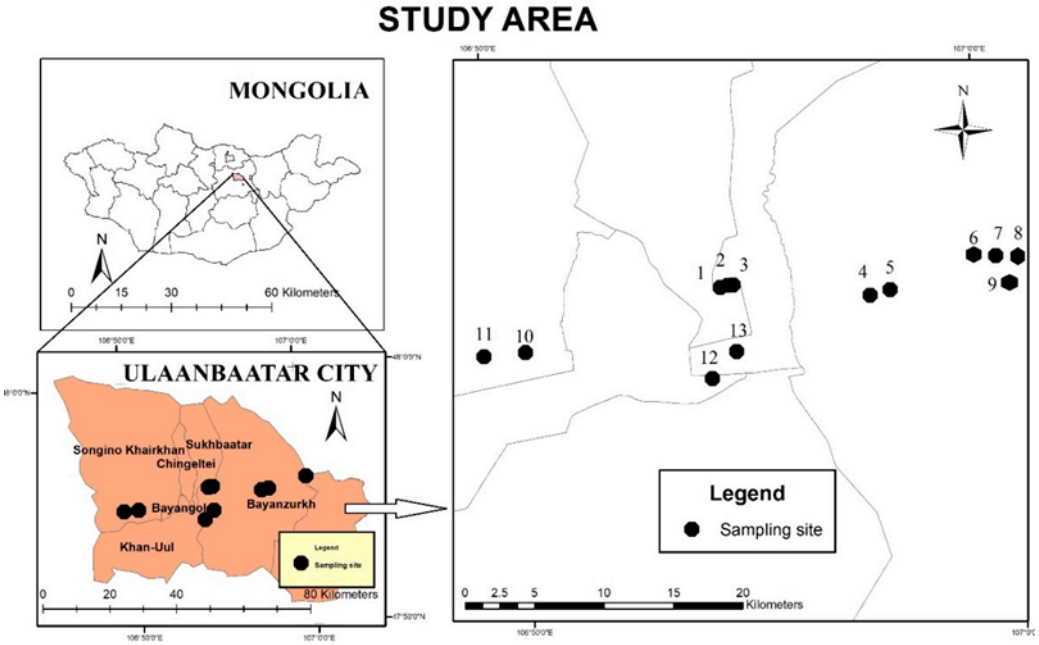


Figure 1. Locations of soil sampling site in Ulaanbaatar, Mongolia

Sample preparation for analysis. The 0.25 g of sample were weighed in a 250 ml Pyrex Erlenmeyer flask and 10 ml of 1:1 HNO3 were added. The solution was heated on a hot plate to ~95 °C without boiling and this temperature was maintained for 10-15 min. After cooling to less than 70 °C, 5 ml of concentrated HNO3 were added and the sample was refluxed at ~95 °C without boiling until the volume was 5 ml. Thereafter, the sample was evaporated to ~5 ml without boiling. After cooling to less than 70 °C, 2 ml of water were added followed by the slow addition of 3 ml of 30% H2O2. The solution was then heated until effervescence subsided. After cooling to less than 70 °C, 10 ml of conc. HCl were added and the sample was refluxed for 15 min. without boiling. After cooling to room temperature, the sample was filtered and

diluted to 25 ml with double distilled water. The prepared sample was analyzed in AAS and results were calculated by Eq1.

$$Element(mg/kg) = \frac{\left(\frac{mg}{mL} in\ sample\ solution\right) x\ (dilution\ factor)}{weight\ of\ sample\ in\ grams} \quad (1)$$

Their potential health risks were evaluated by the US Environmental Protection Agency (USEPA). Due to determine to the source of anthropogenic, the geoaccumulation index was evaluated.

Geoaccumulation index

The geo-accumulation index (I_geo) was introduced by Muller, G (2018) and it enables the assessment of environmental contamination by comparing differences between current and preindustrial concentrations. The geoaccumulation index is calculated by Eq. 2 and consists 7 classes or grades which presented in Table 1 (Li, Z., 2014).

$$I_{geo} = log_2\left(\frac{C_n}{1.5 \cdot B_n}\right) \quad (2)$$

where, C_n – the measured concentration of every heavy metal (mg/kg). B_n – the geochemical background value of the heavy metals found in the soil (mg/kg). In this study, these reference values were obtained from (Kasimov, N. S.,2011) as Cr 66 mg/kg, Cu 42 mg/kg, Pb 27 mg/kg and Zn 52 mg/kg. The constant 1.5 (Loska, K.,et al 2004) was used due to potential variation in the baseline data.

Table 1. Seven Classes Comprising the Geoaccumulation Index.

Class	Value	Soil quality
0	$I_{geo} \leq 0$	Practically uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 3$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$5 < I_{geo} < 6$	Extremely contaminated

Health risk assessment. The health risk assessment was performed to assess the possible risk from contaminated soil by heavy metals for local residents in the vicinity of auto repairing centers near the Ger area of Ulaanbaatar. The health risk assessments, for both adults and children, were analyzed with the USEPA model which is a commonly used to evaluate carcinogenic and non-carcinogenic risk (USEPA,1996, 2001). The corresponding formulae that express the dose received through ingestion, and dermal and inhalation pathways are listed in Table 2.

Table 2. The Equations for Measuring Daily Intake via Various Exposure Pathways.

Pathways	Formula	
Ingestion	$ADI_{Ingestion} = \frac{C\ x\ IngR\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT}$	(3)
Dermal contact	$ADI_{dermal\ contact} = \frac{C\ x\ SA\ x\ FE\ x\ ABS\ x\ EF\ x\ EDxCF}{BW\ x\ AT}$	(4)
Inhalation	$ADI_{inhalation} = \frac{C\ x\ InhR\ x\ EF\ x\ ED}{PEF\ x\ BW\ x\ AT}$	(5)

The parameters used in the health risk assessment are listed in Table 3. The two principal toxicity indices are known as slope factor (SF), and reference dose (RfD). The SF is a conservative estimate of the incremental probability of an individual developing cancer as a result of exposure over a lifetime and RfD is the estimated amount of the daily exposure level for the population that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfD and Slope factor values are utilized in calculations that are based on information issued by the (USEPA Integrated Risk Information System; Kamunda, C.,et al 1998; Huang, S.H.,et al 2017). The toxicity indices of the elements are presented in Table 4.

Table 3. The Parameters Used in the Health Risk Assessment are Listed.

Parameters	Adult	Children	Unit	References
ADI, average daily intake	-	-	[mg/kg day]	-
IngR, soil ingestion rate	100	200	[mg/day]	USEPA 1991
EF, exposure frequency	350	350	[day/year]	USEPA 1991
ED, exposure duration	30	6	[year]	USEPA 2004
BW, body weight	70	15	[kg]	USEPA 2004
SF, skin area exposed to soil contact	5700	2800	[cm^2]	USEPA 2004
AF, soil to skin adherence factor	0.07	0.2	[kg/cm day]	USEPA 2004
ABS, contact factor	0.1	0.1	none	USEPA 2004
InhR, inhalation rate	15	10	[m^3/day]	USEPA 1997
PEF, particle emission factor	$1.36x10^9$	$1.36x10^9$	[m^3/kg]	USEPA 2001
AT, average time non-carcinogenic	10950	2190	[days]	USEPA 2002
AT, average time carcinogenic	25550	25550	[days]	USEPA 2002
CR, Conversion factor	$1x10^{-6}$	$1x10^{-6}$	[mg/kg]	USEPA 2002
FE, Dermal exposure ratio	0.61	0.61	-	USEPA 2004

Table 4. Value of RfD and SF of Heavy Metals

Reference Dose [mg/kg day]	Cr	Cu	Pb	Zn
Ingestion	$3.0x10^{-3}$	$4.0x10^{-2}$	$3.5x10^{-3}$	$3.0x10^{-1}$
Dermal absorption	NA	$1.2x10^{-2}$	$5.3x10^{-4}$	$6.0x10^{-2}$
Inhalation	$1.0x10^{-4}$	NA	NA	NA
Slope Factor [mg/kg day]				
Ingestion	NA	NA	$8.5x10^{-3}$	NA
Dermal absorption	NA	NA	NA	NA

Inhalation	$1.2x10^{-2}$	NA	$4.2x10^{-2}$	NA

NA represents data not available

Non-carcinogenic risk assessment. Non-carcinogenic hazards are typically characterized by the hazard quotient (HQ). The hazard quotient is defined as the quotient of the chronic daily intake, or the dose divided by the toxicity threshold value, which is referred to as the reference dose (RfD) of a specific chemical. The hazard quotient of a single element is determined by Eq. 6.

$$HQ=ADI/RfD \quad (6)$$

To assess the overall potential for non-carcinogenic effects posed by more than one chemical, a hazard index (HI) approach has been applied. For a mixture of contaminants, the hazard index of the mixture is calculated from Eq. 7.

$$HI = \sum HQ = \sum \frac{ADI_i}{RfD_i} \quad (7)$$

If the HI value is less than 1, the exposed population is unlikely to experience obvious adverse health effects. If the HI value exceeds 1, then adverse health effects may occur.

Carcinogenic risk assessment. Carcinogenic risk is estimated by calculating the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The slope factor (SF) converts the estimated daily intake of a toxin averaged over a lifetime of exposure directly to the incremental risk of an individual developing cancer, and is calculated from Eq. 8.

$$Risk=ADI \times SF \quad (8)$$

The total excess lifetime cancer risk for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using Eq.9

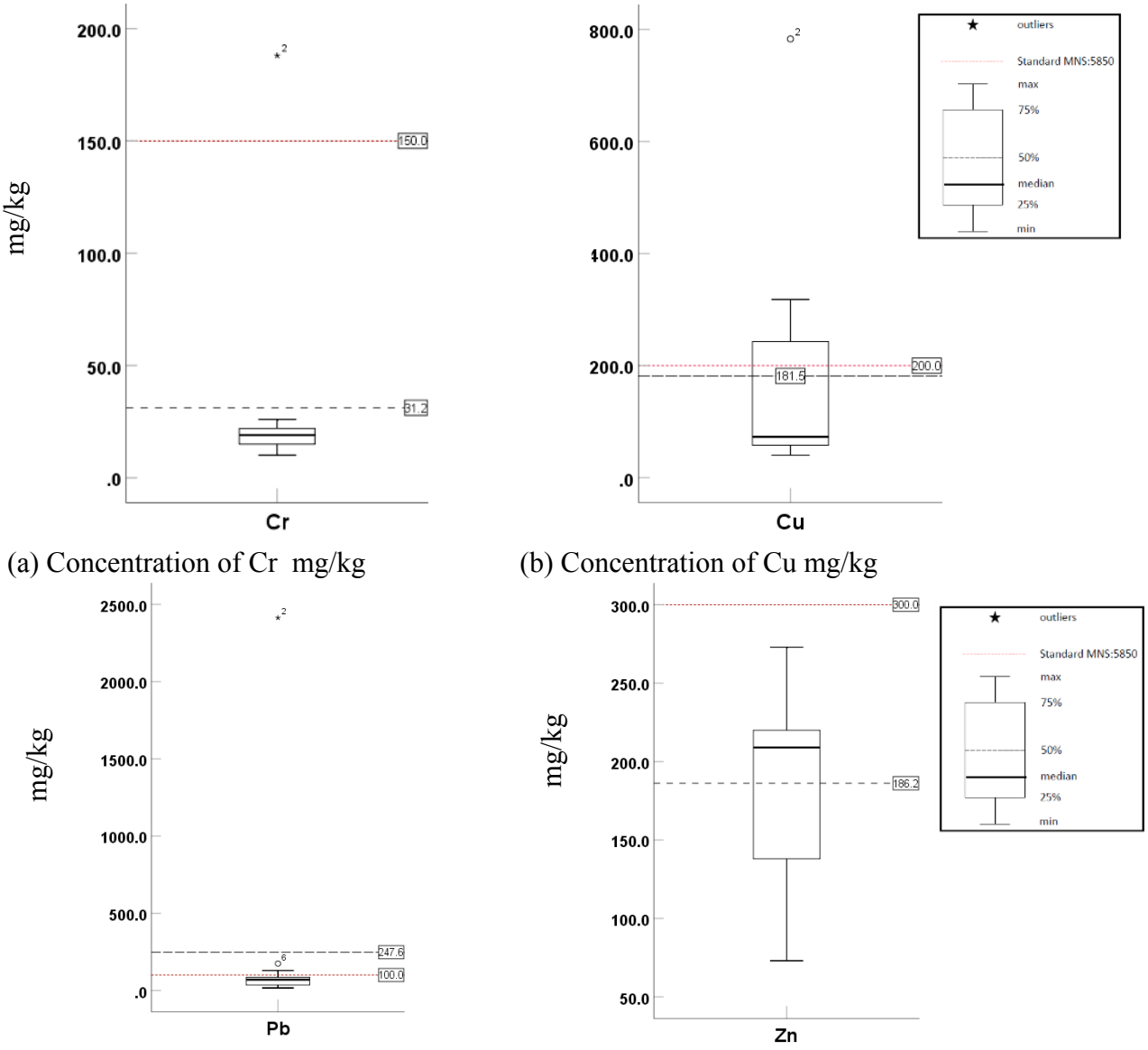
$$Risk(total)=Risk(inh)+Risk(ing)+Risk(dermal) \quad (9)$$

where Risk(ing), Risk (inh), and Risk (dermal) are risk contributions through ingestion, inhalation and dermal pathways. The risk surpassing 1x10-4 is viewed as unacceptable, risk below 1x10-6 is not considered to pose significant health effects, and risks lying between 1x10-4 and 1x10-6 are generally considered an acceptable range, depending on the situation and circumstances of exposure.

Results and Discussion

Results of Concentration of heavy metals in soil from the auto service areas. Concentrations of some heavy metals were higher than the soil standard of Mongolian standard, for example, the concentration of Cr (1 sample), Pb (3 samples), and Cu (5 samples) in total soil samples were 7.7 %, 23.1%, and 46.2% higher than the MNS, respectively, while the concentration of Zn was lower than the soil standard. The results showed that the average concentrations of heavy metals varied and decreased in the order of Cu>Pb>Cr>Zn.

In Figure 2, the mean and median concentration of each heavy metal concentrations in soils are presented. The highest concentration of Cr, Cu and Pb were obtained near at Bayanburd's circle or 2nd sample. There is one of the main areas of auto service centers in Ulaanbaatar city.



(a) Concentration of Cr mg/kg (b) Concentration of Cu mg/kg

c) Concentration of Pb mg/kg (d) Concentration of Zn mg/kg

Figure 2. Boxplots of the Heavy Metal Concentrations (mg/kg).

The concentration of Pb, Zn, Cu and Cr were determined by 16±2413mg/kg, (73±273mg/kg, 40±783mg/kg, and 10±188mg/kg, respectively. For example, for content of Zn was lower than standard for all samples. Moreover, the content of Cr in the samples was not exceeding the MNS, only in the sample 2 or Bayanburd's "Lubricating material" 1.8 times higher than the MNS. On the other hand, the content of Cu was between 40 and 783 mg/kg which is around 2.6 times higher than the MNS. Distribution of Cu has determined at two main areas of the auto market and auto repairs centers such as at the Da Khuree market of Bayanzurkh district and auto repairs centers in Chingeltei district, respectively. The content of Pb was determined higher than MNS by 24 times at sample 2 that area had spilled by the oil of

automobiles when soil samples were collected. It would be a reason why there was determined a higher concentration of Pb than other sampling sites. Moreover, a sample 2nd is located near bayanburd's circle in Chingelte district which is one of the main areas of auto repairs services in Ulaanbaatar city. Individual auto repairs services have been working on their business in this area for a long time. This study is discovered the distribution of Cu, Cr, and Pb was distributed at the district of Bayanzurkh, and Chingeltei.

Result of Index of geoaccumulation (Igeo). According to the geoaccumulation index, 12 samples appear to be in the range of uncontaminated to heavily contaminated. The calculated Igeo for Cu and Pb indicated that only one sampling station for those two elements had an Igeo value greater than 3.6. The maximum index of geoaccumulation of soil in the study area was as high as 5.9, indicating an extremely high contamination risk, which should give rise to widespread concern. Figure 3 and Table 6 shows the index of geoaccumulation in all samples for Cr, Cu, Pb and Zn.

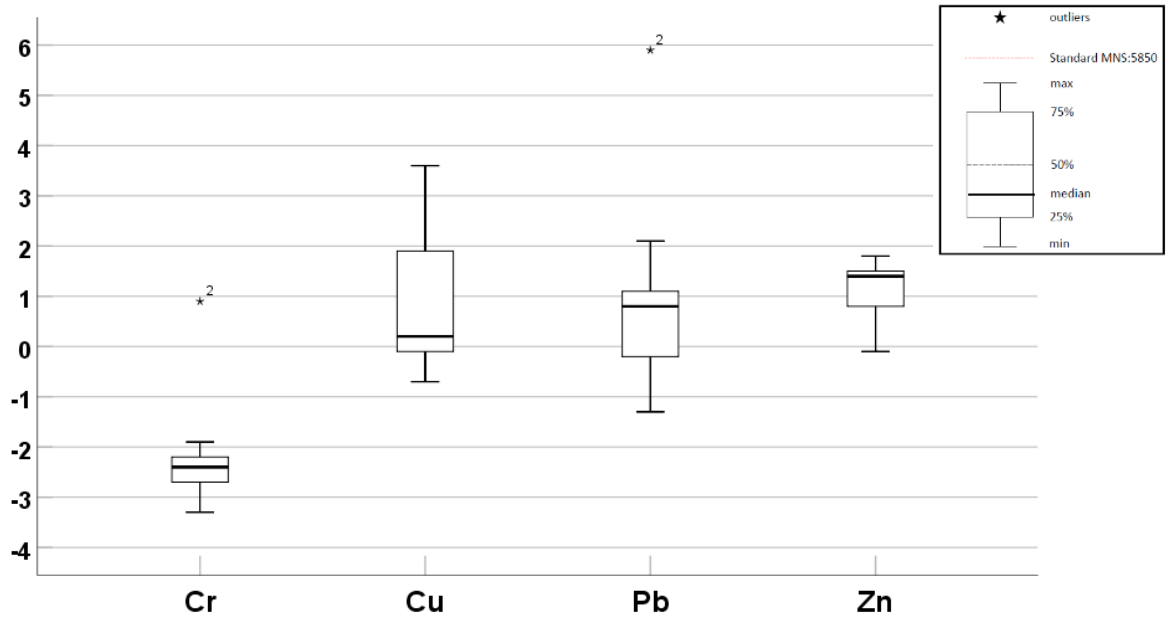


Figure 3. Boxplots of the Geoaccumulation Value for Four Heavy Metals

Human health risk assessment results. The non-carcinogenic and carcinogenic risks posed by Cr, Cu, Pb and Zn in soils of four districts (Bayanzurkh, Chingeltei, Songinokhairkhan and Khan-uul) in Ulaanbaatar area for adult and children, through different exposure pathways (ingestion, dermal contact and air inhalation), were evaluated. Non carcinogenic risk for adults and children were evaluated, as presented by the Hazard Index and Cancer Risk values (Tables 7 and 8).

Non-carcinogenic risk assessment result. Non-carcinogenic hazards or the hazard quotient (HQ) of some pathways were not evaluated by the dermal contact of Cr and the air inhalation of Cu, Pb and Zn because the non-carcinogenic reference dose (RfD) is not available for some pathways. Table 7 and Figure 5 shows that the dermal route posed the highest risk, followed by ingestion interaction and then inhalation of the soil particles. In children, the three different exposure routes caused HI in the sequence for all the metals studied as Zn>Cr>Cu>Pb. The ingestion and inhalation pathways had HQ and HI values greater than 1, for example Cu and Pb had total HI of

equal to 1.23 for all pathways. This value indicates that heavy metal pollution may pose unacceptable non-cancer health risks to children living around the auto services areas. For adults, the same pattern was found except for Pb, which preceded Cu. The remainder of the HI sequence for all of the metals was found to be the same as the calculated values of HQ which were not exceed than 1 in all pathways for adult. This meant that the adult population was no risk of non-carcinogenic effects. The results also indicate that, for children, the dermal pathway contributes the greatest to non-carcinogenic risk, followed by the ingestion pathway. Inhalation is the smallest contributor to the risk. Children interact more with dust and soil particles than adults due to their behavioral activities, playing hours and carelessness with eating and drinking. Special provisions should be made to minimize the exposure of children to such hazardous health situations. According to Table 7, the HI for Pb (1.1 x100) showed the highest non-carcinogenic risk in children followed by Cu (3.6 x10-2), Cr (9.6x10-3) and Zn (7.2 x10-3). Therefore, Pb could be of the most concern regarding the potential occurrence of health hazards. The main sources of these elements are gasoline, hose paint, storage batteries, toys and faucets, the burning of oil and coal, petroleum, fertilizers, oil well drilling and metal plating tanners (Ghani 2011; Thurmer K, 2002). This concern is not only relevant to auto repair centers.

Table 7. Average Daily Intake (ADI) Values in mg/kg/day for Adults and Children in Soil from the Auto Services Area for Non-Carcinogenic Risk Calculations.

Receptor Pathway		Average Daily Intake (ADI) values for heavy metals [mg/kg]				Total Hazard Index
		Cr	Cu	Pb	Zn	
Adult	Ingestion	$2.1x10^{-3}$	$9.3x10^{-4}$	$1.5 x10^{-2}$	$1.3 x10^{-4}$	$1.8 x10^{-2}$
	Inhalation	$3.2x10^{-4}$	-	-	-	$3.2 x10^{-3}$
	Dermal	-	$5.0 x10^{-3}$	$1.6 x10^{-1}$	$1.0 x10^{-3}$	$1.6 x10^{-1}$
	Total	$2.5x10^{-3}$	$6.0 x10^{-3}$	$1.7 x10^{-1}$	$1.2 x10^{-3}$	$1.8 x10^{-1}$
Children	Ingestion	$6.7x10^{-3}$	$2.9 x10^{-3}$	$4.5 x10^{-2}$	$4.0 x10^{-4}$	$5.5 x10^{-2}$
	Inhalation	$2.9x10^{-3}$	-	-	-	$2.9 x10^{-3}$
	Dermal	-	$3.3 x10^{-2}$	$1.03 x10^{0}$	$6.8 x10^{-3}$	$1.1 x10^{0}$
	Total	$9.6x10^{-3}$	$3.6 x10^{-2}$	$1.1 x10^{0}$	$7.2 x10^{-3}$	$1.1 x10^{0}$

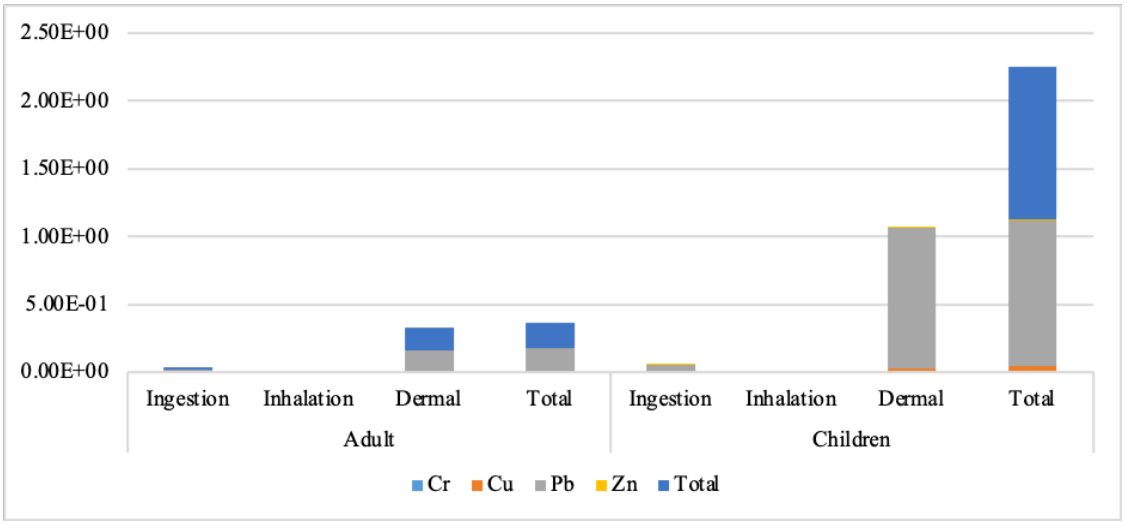


Figure 5. Hazard Quotient (HQ) Values for Heavy Metals in Adults and Children for Soil Form Auto Services Area

Carcinogenic risk assessment. The carcinogenic risk assessment results are listed in Table 8 and Figure 6. Because carcinogenic slope factors (SF) are unavailable in any references for Cu and Zn, the carcinogenic risk was estimated for Pb and Cr. In the case of Pb, the total risk was evaluated by ingestion and inhalation. The total risk by inhalation pathway, for Cr and Pb, was found to be the highest contributor to the cancer risk by the ingestion pathway but it did not pose a risk to human health. The cancer risk for adults was less than 1x10-6 for all pathways. However, for children, only the ingestion pathway had a cancer risk value that was equal to 2.3x10-6, which is considered an acceptable range, while the other two inhalation and dermal pathways were not considered to pose significant health effects. In this study area, children are more at risk than adults due to the dermal pathway. However, only in sample 2 the total cancer risk was estimated to be in an unacceptable range for children, especially with respect to Pb, which can lower energy levels and damage the brain, lungs, kidney, liver, blood composition, and other important organs. Long-term exposure can lead to physical, muscular and neurological degenerative processes that imitate diseases (Jarup L.2003).

Table 8. Average Daily Intake (ADI) values in mg/kg/day for Adults and Children in Soil from the Auto Services Area for Carcinogenic Risk Calculations.

Receptor	Pathway	Average Daily Intake (ADI) Values for Heavy metals in mg/kg				Total Cancer Risk
		Cr	Cu	Pb	Zn	
Adult	Ingestion	-	-	$1.2x10^{-6}$	-	$1.2x10^{-6}$
	Inhalation	$1.6x10^{-10}$	-	$4.5x10^{-9}$	-	$4.7x10^{-9}$
	Dermal	-	-	-	-	-
	Total	$1.6x10^{-10}$	-	$1.2x10^{-6}$	-	$1.2x10^{-6}$
	Inhalation	$3.0x10^{-10}$	-	$8.4x10^{-9}$	-	$8.7x10^{-9}$
	Dermal	-	-	-	-	-
	Total	$3.0x10^{-10}$	-	$2.3x10^{-6}$	-	$2.3x10^{-6}$

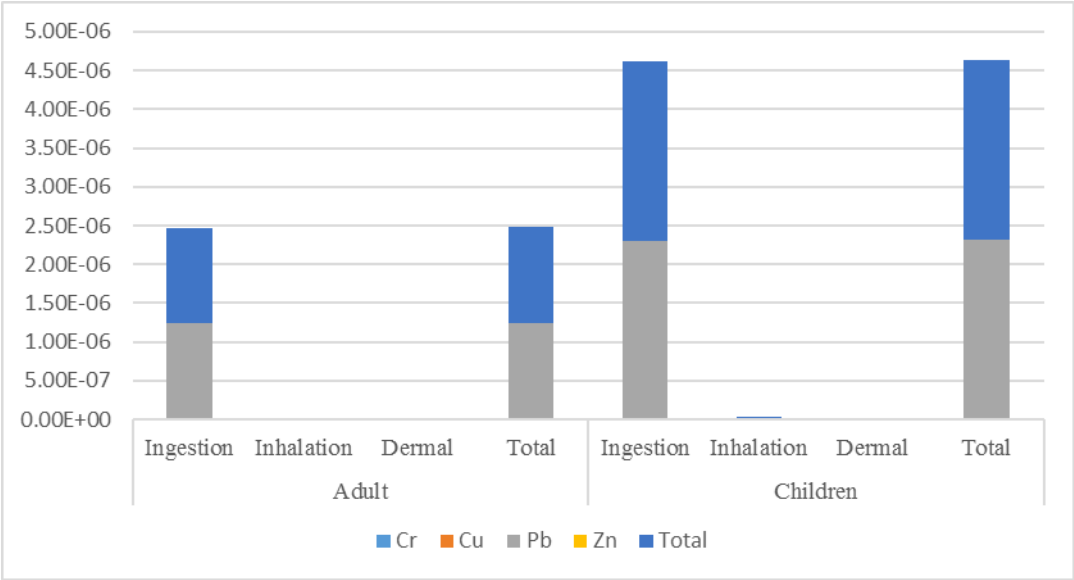


Figure 6. Cancer Risk (CR) Values for Heavy Metals in Adults and Children for Soil Form Auto Services Area

On the other hand, the children did not only affect the dermal pathway in the ger district but also exposed by the inhalation pathway, especially in wintertime. Most particulates form in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted from power plants, industries, and automobiles. For example, the Ger area and traffic are the main pollution sources of SO2 and NO2 (Huang, Y.K.,). Moreover, the contribution of PM2.5 was sourced from soil 47%, coal combustion 35%, motor vehicles/road dust 13%, and biomass burning 4% in resident's area (Gunchin, G.,2012). Therefore, ger residents, who live near auto services centers may occur living not only the skin but also inhalation factors in the risk area due to soil pollution.

Conclusions

One of the biggest sources caused environmental pollution is open and inconvenient auto repair and maintenance service centers in Ulaanbaatar city. In order to identify soil pollution, we found out toxic substances /Cr, Cu, Pb, Zn/from the soil samples of Bayanburd in Chingeltei district, Ikhzasag University, and Million students dormitory in Bayanzurkh district, Da Khuree in Bayanzurkh district, Tavanshar area auto repair centers in Songinokhairkhan district. In the taken sample's soil, toxic elements amount was performed 24-70 times more than Mongolian Standard. Lately, lead and fuel products are included as one of the polluted anthropogenic sources. The survey was shown that the content of lead is 14-2413 mg/kg, an average of 67,1 mg/kg in the soil of the Ulaanbaatar auto repair center area. It has been 24 times exceed the accepted level. The average oil product content in soil is 14,4 %. It's considered 70 times exceed the Mongolian national standard. The concentration of Cr was 10.5-188 mg/kg, an average of 31.2mg/kg, but in the Bayanburd area's some points soil Cr is 1.8 times exceed the acceptable level of Mongolian standard. Copper concentration was 40-782.5 mg/kg. The health risk for both adults and children were evaluated to define the possible risk from soil contaminated by heavy metals near auto repairing centers in the Ger area of Ulaanbaatar city.

The human health risk assessment found that all soil samples were ranged by unacceptable at non-carcinogenic risks for adults and children. Carcinogenic risks were ranged to not significant risks all of the samples except sample no 2. But the only sample no 2 posed acceptable carcinogenic risks, especially for children.

The results of this study will help to contribute to a database for future monitoring and development of environmental standards for auto services in Ulaanbaatar city, Mongolia. This study could assist with strategic planning and management aimed at reducing heavy metal contamination in soil from near auto services and the risk to public health in the Ger area of Ulaanbaatar city.

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Assessment of Thermal Comfort and Microclimate in Urban Street Canyons – A Review of Recent Research

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Abstract
Streets are among the major components of Cities where walkability and livability can be enhanced by creating comfortable environments. But, as the global mean surface and air temperature have been projected to increase during this century, the intensity of corresponding extreme thermal stress events are also expected to rise thus making significant contributions towards global warming in the foreseeable future. This paper is based on recent studies on assessing microclimate and thermal comfort in urban street canyons. The results of recent research concluded that the street morphology, properties of street surfaces, vegetation cover are the main design factors, and Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH), and Mean radiant temperature (MRT) are the dominant meteorological parameters affecting the level of thermal comfort. Street aspect ratios H/W, sky view factor (SVF), and Street axis orientation are key parameters of street morphology, while the parameters of vegetation are categorized into Geometry, density, configuration, and physical properties of plants. Furthermore, surface albedo, color, and reflectance are identified under the properties of street surfaces. The tendency of recent research approaches has been to rely on simulation modeling with reference to different design scenarios employing specified thermal comfort indices. Further, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous research. By the end of this review, ENVI-met micro-meteorological simulation model employing Physiological Equivalent Temperature (PET) is suggested for future research on microclimatic improvements in street canyons.

Keywords: Street Canyons, Thermal Comfort Assessment, Microclimate, ENVI Met, PET, Global Warming

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Background

As the global mean surface and air temperature have been projected to increase during this century by 2.6 C - 4.8 C and 2 C - 4 C, respectively especially in urban areas (Brysse, K., Oreskes, N., O'Reilly, J., & Oppenheimer, M. 2013), the intensity of corresponding extreme thermal stress events are also expected to rise thus making significant contributions towards global warming in the foreseeable future. The frequency of urban heat island (UHI) characterized by high air and surface temperatures in urban areas is significantly increasing as a consequence of rapid urbanization and global warming, (Brysse et al., 2013). This affects to increase air temperatures, resulting in a higher request for cooling, a decline in air quality, and a reduction in human thermal comfort (Zhao, Sailor, & Wentz, 2018).

Since half of the world population lives in the tropics, (EIU, 2011) significant attention should be paid to high temperature, humidity, and high solar radiation to urban context within the tropics. It will cause heat stress to urbanites, resulting in negative impacts on public health and productivity (Yang, W., Lin, Y., & Li, C. Q. 2018). Further, this trend of world's population growth will inevitably have a strong impact on the sustainability and the energy costs of the built environment (Chen, L., & Ng, E. 2012). Consequently, urban planners, landscape architects and environmental policy makers have been getting involved and implementing several modifications of built environment with alteration of surface materials, urban morphology, irrigation systems and greenery for facilitating urbanites (Morakinyo, T. E., & Lam, Y. F. 2016). As urban design has a significant impact on microclimate and outdoor thermal comfort, (Yahia, M. W., Johansson, E., Thorsson, S., Lindberg, F., & Rasmussen, M. I. 2018) urban morphology influences urban microclimate, and vice versa. Therefore, Climate responsive urban design has become an important and urgent task in the cities. This calls for designing and maintenance of thermally comfortable outdoor urban environments with alteration of urban morphology, material and inclusion of greenery (Akbari, H., Bretz, S., Kurn, D. M., & Hanford, J. 1997), Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. 2015). It has been recognized that the urban microclimate which is influenced by several design factors, is an effective issue on the local and global climate change.

However, considering the public realm, Streets are among the major components of Cities where walkability and livability should be enhanced by creating comfortable environments. But, alteration of building masses, lack of space for planting and hard surface improvements affect the changes of microclimate of street canyons. Cities are composed of street canyons with different uses, functions and composed with various elements, material compositions and morphologies. These factors creating significant impact on microclimate of such cities is an amalgam of thermal comfort in street canyons as highlighted in recent research. The street canyon landscape is considered important to improving the thermal environment and has become a key research topic in landscape architecture (Li, G., Ren, Z., & Zhan, C. 2020). Therefore researching on assessment of thermal comfort and microclimate in urban street canyons and rethinking on the parameters, methodologies and approaches adapted to the particular domain is significant. This paper is based on the recent studies of assessing microclimate and thermal comfort in urban street canyons in the past decade (2010 to 2020). The objectives of the study are, to critically examine previous efforts of

assessing microclimate and thermal comfort in urban street canyons, to determine the key parameters affecting street canyon microclimate and thermal comfort and to identify areas where previous research is inadequate, and explore future research trends through a comprehensive literature analysis.

Methodology

This research is conducted through a comprehensive literature review of papers on the assessment of urban canyon microclimate and thermal comfort, published from 2010 to 2020 (Past decade). Papers which were screened through Scopus database, were reviewed manually through Content analysis, to identify key design and climatic parameters and methods which were adapted to assess urban street canyon microclimate and thermal comfort.

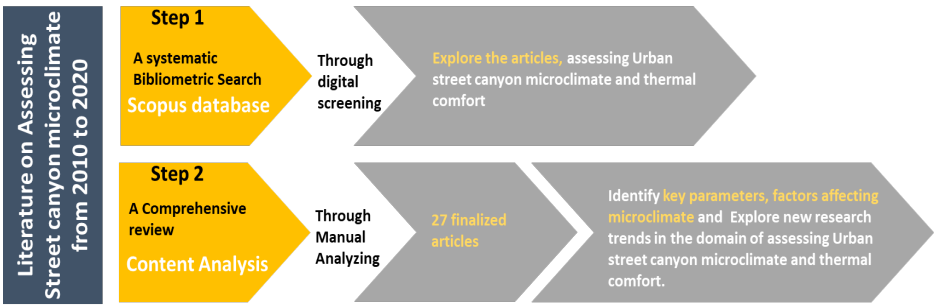

Figure 1: Methodological Approach

Analysis were conducted in two steps. First, a systematic bibliometric search was conducted through digital screening to explore related articles from the Scopus database in this particular research domain. In the second step, 27 articles were finalized through manual screening and conducted a comprehensive content analysis to identify key parameters and factors affecting street canyon microclimate and thermal comfort, methodologies adopted, research areas where previous research is inadequate, and to explore future research trends and explore new research trends.

Content Analysis

The papers reviewed in this study have been published in various journals, but the two journals mostly used are: Building and Environment and Sustainable City and Society. The results of these studies are categorized in terms of their titles, in order to find gaps and areas that have received less research attention. Table 1 shows a summary of the review of the most relevant articles related to assessing urban street canyon microclimate and thermal comfort, the main topic under research, the key parameters used and the methodologies adapted. The main focus of these articles was on assessing the impact of street morphology parameters, properties of street surfaces and parameters of vegetation cover on the street canyon microclimate. Along with this analysis, dominant meteorological parameters affecting the level of thermal comfort which are widely used as the inputs of micro-meteorological simulation software were identified. Key parameters used in these studies can be categorized into two main streams namely, Street canyon design factors and meteorological factors.

No	Author(s) and year	Title	Publishing journal	Key parameters	Methodology
1	Morakinyo et al., (2017)	A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort	Building and Environment	Leaf area index - Tree height - Trunk height - Crown height and width	ENVI-met V4.0 and RayMan1.2 models + Physiological Equivalent Temperature (PET)
2	Morakinyo, T. E., & Lam, Y. F. (2016)	Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort	Building and Environment	varying aspect ratio (ARB) with embedded trees of varying aspect ratio (ART), leaf area index (LAI), leaf area density (LAD) distribution and trunk height	Micrometeorological model, ENVI-met. Employing physiological equivalent temperature (PET), the in canyon thermal comfort was characterized
3	Shafaghat et al., (2016).	Environmental-conscious factors affecting street microclimate and individuals' respratory health in tropical coastal cities	Sustainable Cities and Society	Sky view factor (SVF), Ratio (H/W), Street orientation, Surface albedo (SA), Asymmetrical shapes, Color of ground and facades, Material of the ground & facades, Shade and shadow, Air pollution, Vegetation, Luminous environment, Traffic load	A Literature review
4	Fabbri et al., (2020)	Effect of facade reflectance on outdoor microclimate: An Italian case study	Sustainable Cities and Society	reflectance , Color	outdoor microclimate was modelled with Envi-met V.4.4
5	Rodrígue et al., (2018).	Effect of asymmetrical street canyons on pedestrian thermal comfort in warm-humid	Theoretical and Applied Climatology	height-to-width ratio, street axis orientations (N-S, NE-SW, E-W, SE-NW), Asymmetrical	Temporal-spatial analyses are conducted using the Heliodon2 and the RayMan model

		climate of Cuba		street aspect ratios	
6	Roshan, G., Moghbel, M., & Attia, S. (2020).	Evaluating the wind cooling potential on outdoor thermal comfort in selected Iranian climate types	Journal of thermal biology	Factors that influence urban thermal comfort Design factors - Urban Morphology, Sky veiw factor, Shade coverage, Vegetation and water, Street aspect ratio, Reflectivity,	The physiologically equivalent temperature (PET) index and the RayMan model software.
7	Moohammed et al., (2017)	Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam, Tanzania	Int J Biometeorol	building heights and orientations, spaces between buildings, plot coverage alter solar access, wind speed and direction at street level	physiologically equivalent temperature (PET) are simulated using ENVI-met
8	Ruiz et al., (2017)	Design tool to improve daytime thermal comfort and nighttime cooling of urban canyons	Landscape and Urban Planning	Solar permeability , Number of trees (NT), Trees per meter (T/m), Mean tree height (MTH), Tree cover (TC), Tree view factor (TVF), Urban canyon, length (UCL), Volume/Width (V/W), Urban canyon width (UCW), Volume/Length (V/L), Mean building height (MBH) , Height/Width (H/W), Building view factor (BVF) , Sky view factor (SVF), Vertical surface albedo (VA), Horizontal surface albedo (HA)	A linear multivariate thermal comfort model called the COMFA-tool was created

9	Erell et al., (2014)	Effect of high-albedo materials on pedestrian heat stress in urban street canyons	Urban Climate	Canyon aspect ratio, Canyon orientation, Surface albedo, Geographic location and climate	thermal comfort (represented by the Index of Thermal Stress) is calculated using detailed microclimatic input data simulated by a canyon model (CAT)
10	Qaid et al., (2018).	Effect of the position of the visible sky in determining the sky view factor on micrometeorological and human thermal comfort conditions in urban street canyons	Theoretical and Applied Climatology	Sky view factor, Street orientation, H/W Aspect ratio,	Investigated by applying ENVI-met V3.1 Beta software.
11	Qaid, A., & Ossen, D. R. (2015)	Effect of asymmetrical street aspect ratios on microclimates in hot, humid regions	Int J Biometeorol	asymmetrical aspect ratio, sky view factor, Street orientation, street H/W aspect ratio	Envi-met three-dimensional microclimate model (V3.1 Beta).
12	Lobaccaro et al., (2019).	Effects of Orientations, Aspect Ratios, Pavement Materials and Vegetation Elements on Thermal Stress inside Typical Urban Canyons	International Journal of Environmental Research and Public Health	Street orientations, height-to-width aspect ratios, pavement materials, trees' dimensions and planting pattern	evaluation of Physiologically Equivalent Temperature using ENVI-met
13	Zaki at al., (2020).	Efects of Roadside Trees and Road Orientation on Thermal Environment in a Tropical City	sustainability	sky view factor, road orientation,	Field measurements were conducted to assess outdoor thermal environments + PET

14	Lee, H., Mayer, H., & Kuttler, W. (2020)	Impact of the spacing between tree crowns on the mitigation of daytime heat stress for pedestrians inside EW urban street canyons under Central European conditions.	Urban Forestry & Urban Greening	Crown coverage, aspect ratios (H/W), Street orientations, Space between trees, tree location	ENVI-met model v4.0 BETA + Human thermal comfort is determined by the mean radiant temperature (Tmrt) and physiologically equivalent temperature (PET)
15	Deng, J. Y., & Wong, N. H. (2020)	Impact of urban canyon geometries on outdoor thermal comfort in central business districts	Sustainable Cities and Society	orientation and aspect ratio, Sky view factor	ENVI-met V3.1 + physiologically equivalent temperature (PET)
16	Bourbia, F., & Boucheriba, F. (2010)	Impact of street design on urban microclimate for semi - arid climate (Constantine)	Renewable Energy	height/width ratio, sky view factor (SVF) and the orientation	series of site measurements
17	Sanusi et al., (2017)	Microclimate benefits that different street tree species provide to sidewalk pedestrians relate to differences in Plant Area Index	Landscape and Urban Planning	Plant Area Index (PAI), leaf characteristics, tree species, Street orientation, Canopy Width, Canopy Shape	Physiological Equivalent Temperature (PET) was estimated to indicate pedestrian thermal comfort. Microclimate conditions were measured
18	Rosso et al., (2018).	On the impact of innovative materials on outdoor thermal comfort of pedestrians in historical urban canyons	Renewable Energy	Sky view factor, materials' albedo	ENVI-met + findings are confirmed by PMV and MOCI analyses
19	Achour-Younsi, S., & Kharrat, F. (2016)	Outdoor thermal comfort: Impact of the geometry of an urban street canyon in a Mediterranean	Social and Behavioral Sciences	streets H/W ratios, different orientations, sky view factor (SVF)	ENVI-met + The assessment of the outdoor thermal comfort was based on the Universal

		subtropical climate – Case study Tunis, Tunisia			Thermal Climate Index (UTCI)
20	Morakinyo et al., (2020).	Right tree, right place (urban canyon): Tree species selection approach for optimum urban heat mitigation - development and evaluation	Science of the Total Environment	tree forms, Tree species, urban morphology – Sky-View Factor (SVF), tree height, trunk height , foliage density and crown diameter, Street orientation, Surface albedo	ENVI-met model employing Physiological Equivalent Temperature (PET)
21	Li, G., Ren, Z., & Zhan, C. (2020)	Sky View Factor-based correlation of landscape morphology and the thermal environment of street canyons: A case study of Harbin, China	Building and Environment	Sky View Factor (SVF), planting space between trees, , The leaf area index (LAI) - refers to the ratio of the total area of plant leaves to the area of land within a unit of land area, leaf area density, LAD is defined as the ratio of the total leaf area to the unit volume in different levels of the canopy.	validated by field measurement data, this research conducted numerical simulations via the micro-climate model ENVI-met (V4.4.2) was adapted
22	Algecira s, J. A. R., Consueg ra, L. G., & Matzara kis, A. (2016)	Spatial-temporal study on the effects of urban street configurations on human thermal comfort in the world heritage city of Camagüey-Cuba	Building and Environment	aspect ratio and street orientation, Sky view factor	RayMan model + employing Physiological Equivalent Temperature (PET)
23	Chatzidi mitriou, A., & Yannas, S. (2017).	Street canyon design and improvement potential for urban open spaces; the	Sustainable Cities and Society	Street canyon geometry Canyon axis orientation Canyon aspect ratio	RayMan software + Physiologically Equivalent Temperature PET

		influence of canyon aspect ratio and orientation on microclimate and outdoor comfort			
24	Venhari, A. A., Tenpierik, M., & Taleghani, M. (2019).	The role of sky view factor and urban street greenery in human thermal comfort and heat stress in a desert climate	Journal of Arid Environments	Sky view factor, Street orientations, Type of greenery, greenery arrangement	field measurements and ENVI-met 3.1 was employed with Physiological Equivalent Temperature (PET)
25	Lamarca, C., Qüense, J., & Henríquez, C. (2018).	Thermal comfort and urban canyons morphology in coastal temperate climate, Concepción, Chile	Urban Climate	sky view factor, shadow factor of buildings	Actual Sensation Vote (ASV) method is used by conducting field measurements
26	Andreou, E. (2013)	Thermal comfort in outdoor spaces and urban canyon microclimate	Renewable Energy	Orientation, height/width ratio, Effect of trees, Wind speed, Albedo of the horizontal surface	Rayman v.1.2 tool + physiologically equivalent temperature (PET)
27	Muniz-Gäal et al., (2020)	Urban geometry and the microclimate of street canyons in tropical climate	Building and Environment	aspect ratio (H/W), length-to-height (L/H) ratio	ENVI-met 4.0 + physiological equivalent temperature (PET)

Table 1: List of key parameters and methodologies adapted in recent studies (2010 to 2020)

Results and Discussion

Identified key parameters of design factors can be categorized into three criteria as Street morphology, Properties of street surfaces and Vegetation cover. Meteorological parameters which are widely used as the inputs of meteorological simulation software are, Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH), Mean radiant temperature (MRT). According to these findings, Street aspect ratios H/W, sky view factor (SVF), and Street axis orientation are key parameters of street morphology, while the parameters of vegetation are sub categorized into Geometry, density, configuration, and physical properties of plants. Furthermore, surface albedo, color, and reflectance are identified under the properties of street surfaces. Figure 2 illustrates the key parameters of Design factors.

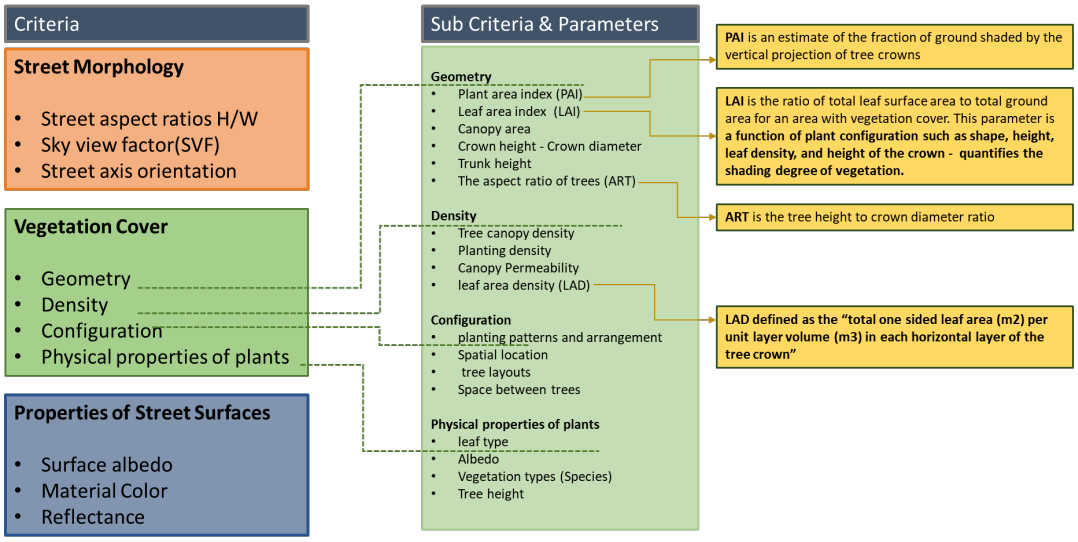

Figure 2: Key Parameters of Design Factors

Some of the parameters such as Plant area index (PAI), Leaf area index (LAI) and tree aspect ratio (ART) have been developed combined with several characteristics of trees. PAI is an estimate of the fraction of ground shaded by the vertical projection of tree crowns (Sanusi, R., Johnstone, D., May, P., & Livesley, S. J. 2017). LAI is the ratio of total leaf surface area to total ground area for an area with vegetation cover. This parameter is a function of plant configuration such as shape, height, leaf density, and height of the crown which quantifies the shading degree of vegetation. ART is the tree height to crown diameter ratio. LAD defined as the "total one sided leaf area (m2) per unit layer volume (m3) in each horizontal layer of the tree crown (Morakinyo et al., 2016).

Design Factors that Affect Thermal Comfort in Urban Street Canyon

Street Morphology

Most of the recent studies of assessing urban street canyon microclimate and thermal comfort have focused on the impact of urban morphology (geometry) factors. Among the studies, Street aspect ratios (H/W), Sky view factor (SVF) and Street axis orientation are significant as the most influential parameters. Recent research findings

reveal that, pedestrian level thermal comfort improves within higher H/W aspect ratio canyons which increases the wind speed and shading by buildings (Muniz-Gäal, L. P., Pezzuto, C. C., de Carvalho, M. F. H., & Mota, L. T. M. 2020). Further, Streets with deep canyons are more comfortable (Achour-Younsi, S., & Kharrat, F. 2016). Moreover, the position of the visible sky has a greater impact on the street's microclimate and human thermal comfort conditions than the SVF value. It has the capability of changing the mean radiation temperature (Tmrt, °C) and the physiological equivalent temperature (PET, °C) at street level (Qaid, A., Lamit, H. B., Ossen, D. R., & Rasidi, M. H. 2018). Furthermore, improving microclimate of urban space, modification of the landscape morphology of the street canyon is the ideal method which does not require changing the forms of existing buildings (Li, G., Ren, Z., & Zhan, C. 2020). Additionally, Lobaccaro et al., 2019 has demonstrated that orientation and aspect ratio strongly affect the degree and extent of the thermal peaks at pedestrian level. But still, asymmetrical street aspect ratios have received less research attention in urban climate studies (Qaid, A., & Ossen, D. R. 2015). The effect of the SVF on the E-W streets was more significant than in N-S streets. Further, the greenery arrangement and building heights showed different impacts on the outdoor thermal comfort of streets with different orientations (Venhari, A. A., Tenpierik, M., & Taleghani, M. 2019). According to Erell, E., Pearlmutter, D., Boneh, D., & Kutiel, P. B. 2014 deeper street canyons have less hours of heat stress and in particular fewer hours of very hot conditions for all combinations of orientation. But N-S street canyons offer equal or better thermal comfort than the equivalent E-W streets for all combinations of canyon aspect ratio. The PET results of all these studies indicate an explicit relationship between canyon geometries and outdoor thermal comfort.

Properties of Street Surfaces

Surface Albedo, material color and reflectance have been discussed in previous studies. Especially in cities in warm climate, wide use of high-albedo materials has been promoted as a means of mitigating the urban heat island effect. Even though, use of high-albedo materials for urban surfaces may reduce the air temperature in pedestrian level, their radiant balance with the environment is also affected. The net effect of increasing the albedo of urban surfaces may thus result in an increase in the thermal stress to which pedestrians are exposed (Erell et at., 2014). Design scenarios with high albedo materials are the best in terms of improving thermal comfort. But this particular application on the vertical surfaces of narrow canyons can lead to adverse effects on outdoor thermal comfort (Rosso et al., 2018). Fabbri, K., Gaspari, J., Bartoletti, S., & Antonini, E. (2020) has investigated how different reflectance values may impact on the outdoor temperature in the spaces narrowing the building by using the relation between the color of some building façade options and the potential effect on the outdoor microclimate. The outcomes indicates that there is a correlation between the building façade reflectance and the temperature tendency but this has a very limited influence on outdoor microclimate.

Vegetation Cover

Effective use of vegetation in urban areas is one of the efficient tools which could be used to reduce urban heat island and to improve thermal comfort due to local climate change and urbanization. Different plant species and their morphological properties affects to solar reduction capacity and accordingly, thermal comfort changes. Among

all tree configuration parameters, leaf area index, tree height and trunk height are the most influential in improving microclimate and thermal comfort, respectively (Morakinyo, T. E., Kong, L., Lau, K. K. L., Yuan, C., & Ng, E. 2017).The role of different plant species on thermal comfort has been assessed using different physical properties of plants, geometry and shadow casting parameters. Figure 3 shows hemispherical photographs of the eight (8) tree species studied and Table 2 shows the physical configuration of the said tree species.

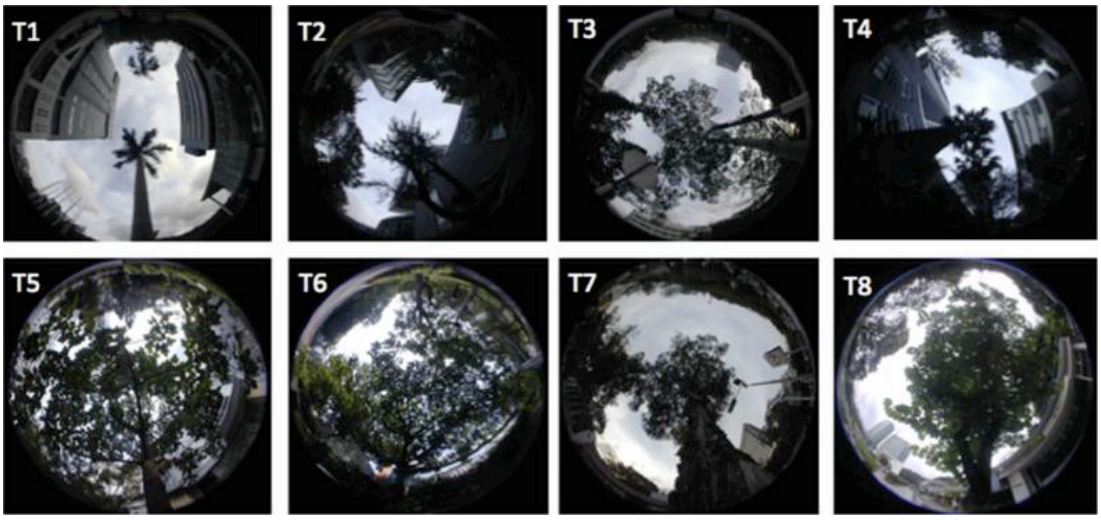

Figure 3: Hemispherical Photographs of the Studied Eight (8) Tree Species.

Tree code	Species name	Leaf type	HT (m)	TH (m)	CH (m)	CW (m)	LAI (m2/m2)	TM 5(%)
T1	Roystonea regia	Evergreen	13	9	4	6	1.1	51.6
T2	Casuarina equisetifolia	Evergreen	14	4	10	7	1.52	30.3
T3	Bombax malabaricum	Deciduous	6	3	3	7	1.83	35.5
T4	Livistona chinensis	Evergreen	11	6	5	6	2.1	23.0
T5	Aleurites moluccana	Evergreen	9	3	6	7	2.77	18.6
T6	Macaranga tanarius	Evergreen	4	1	3	8	3.02	16.2
T7	Melaleuca leucadendron	Evergreen	11	3	8	6	3.42	23.5
T8	Bauhinia blakeana	Evergreen	7	2	5	6	3.55	10.6

Table 2: Physical Configuration of Studied Tree Species (Morakinyo Et Al., 2017). HT: Height of the tree; TH: Trunk height; CH: Crown height; CW: Crown diameter width; LAI: Leaf area index; TM: Transmissivity of downward radiation (%).

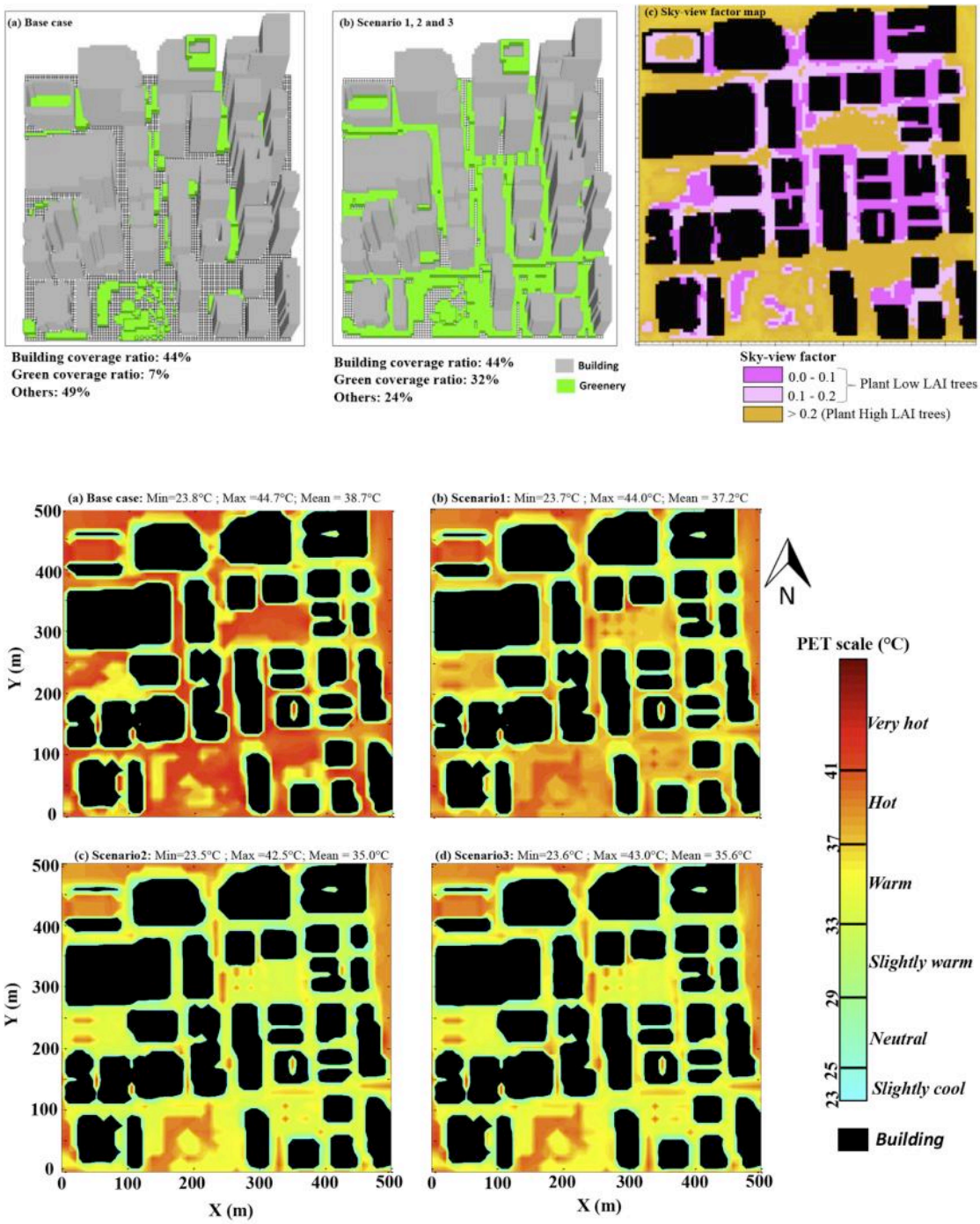

Figure 5: Assessment of Greenery Coverage Effects on Physiological Equivalent Temperature (Morakinyo Et Al., 2017).

According to Sun et al., (2017), Zhang, L., Zhan, Q., & Lan, Y. (2018) trees with greater crown diameters and taller trees can improve thermal comfort. But taller trees with larger trunks and lower crown diameters are appropriate in environments with high urban densities (Morakinyo et al., 2017). Trees totally exposed to sun light can create more cooling effects than those in the shade of the buildings, since the location of trees affects short-wave radiation (Wu, Z., & Chen, L. 2017).

For best cooling effects the species and location within the urban landscape are essential factors for the planning and design of vegetation cover because, heat

mitigation potential of trees varies due to the same factors (Morakinyo, T. E., Ouyang, W., Lau, K. K. L., Ren, C., & Ng, E. 2020). Further, permeable trees with wider crown give greater thermal benefits in reducing temperatures and thermal comfort improvements when compared to dense planting (Zhang et al., 2018). In addition, trees' effectiveness in improving daytime thermal comfort reduces with increasing urban density and vice-versa for nighttime (Morakinyo et al. 2017). Figure 5 shows how the Greenery coverage changes effects on physiological equivalent temperature in selected canyon morphology. Determining the microclimatic and PET benefits, variation in Plant area index (PAI) are prominent (Sanusi et al., 2017). Roadside trees provided greater cooling potential in E–W and NW–SE oriented roads (Zaki et al., 2020). In an urban space, heat reduction possibility of a tree depends on the type of species, tree forms and its location within the urban domain. Among the tree morphological characteristics such as tree height, trunk height, and crown diameter, the main factor of heat reduction efficiency is the foliage. (Morakinyo et al., 2018). However, a local tree inventory and descriptive statistics are required to translate to tree forms to actual tree species for implementation. Tree species with high foliage density act as high heat reducers and vice-versa for low foliage density trees. However, depending on the location, the heat reduction potential of trees can be vary (Morakinyo et al., 2020).

In the research papers reviewed, plant geometry, physical properties of plants, vegetation configuration and density factors were identified as the design factors affecting urban street canyon microclimate. Among these factors, the strongest focus was on physical properties of plants and density. The vegetation configuration parameters have not received sufficient research attention. Therefore, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous studies yet and it is worthy of consideration for further research.

Research Methods Adapted in Simulations

According to the reviewed studies, shown in figure 2 and 3, different methodological approaches have been used and most of them are combination of micrometeorological simulations coupled with thermal comfort indices. All the combinations for assessing thermal comfort and microclimate of street canyons were identified as ENVI-met 4.0 + physiological equivalent temperature (PET), RayMan v.1.2 tool + physiologically equivalent temperature (PET), Actual Sensation Vote (ASV) method + conducting field measurements. In addition, field measurements and ENVI-met employed with Physiological Equivalent Temperature (PET), ENVI-met + the Universal Thermal Climate Index (UTCI), ENVI-met + findings are confirmed by PMV and MOCI analyses have been adapted. Further, thermal comfort (represented by the Index of Thermal Stress) is calculated using detailed microclimatic input data simulated by a canyon model (CAT). Moreover, A linear multivariate thermal comfort model called the COMFA-tool and Temporal-spatial analyses using the Heliodon2 and the RayMan model, and ENVI-met V4.0 and RayMan1.2 models + Physiological Equivalent Temperature (PET) have been used for micrometeorological simulations and signifying thermal comfort levels. However, among all these combinations, ENVI-met micro-meteorological simulation model employing Physiological Equivalent Temperature (PET) was found to be the most prominent research method in assessing microclimate and comfort in urban street canyons.

Conclusion

This paper is based on the recent studies of assessing microclimate and thermal comfort in urban street canyons in the past decade (2010 to 2020) to critically examine previous efforts of assessing microclimate and thermal comfort in urban street canyons. According to the above exercise, parameters affecting thermal comfort and microclimate in urban street canyons are found to be meteorological and design factors. The key parameters of design factors thus identified can be categorized into three criteria, namely, Street morphology, Properties of street surfaces and Vegetation cover. Dominant meteorological parameters which are widely used as the inputs of meteorological simulation software are, Air temperature (Ta), Wind speed, Wind direction, Relative humidity (RH) and Mean radiant temperature (MRT). The tendency of recent research approaches has been to rely on micro-meteorological simulation modeling with reference to different design scenarios employing specified thermal comfort indices relevant to specific climatic regions. At the conclusion of this review, ENVI-met micro-meteorological simulation model employing with Physiological Equivalent Temperature (PET) is suggested for future research on microclimatic improvements in street canyons. Therefore, thermal comfort assessment coupled with different vegetation configurations, street-level ventilation, and varied asymmetrical street aspect ratios have not received adequate attention in previous studies yet and it is worthy of consideration for further research.

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BioTRIZ: Subsidies for Projects in Biomimicry and Design

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Abstract
Biomimicry combines multiple perspectives from the biological sciences to generate creative productions through emulations of nature. In this sense, the integration of tools of such field in the design area is valuable and it would, ultimately, stimulate the transformation of the production cycles so that they can resemble the rich systems of the biosphere. Therefore, the present work aims to investigate the relevance of the applications of biomimicry tools in design, and, more specifically, the use of the BioTRIZ matrix, through a literature review. Therefore, the descriptor 'BioTRIZ' was used in international databases. On the Web of Science, 6 publications were obtained in the period from 2008 to 2020. 8 works were found in Scopus between 2008 and 2020. In Google Scholar, a search for Brazilian contributions was conducted in the same period of the aforementioned repositories, totaling 4 publications. The prevalence of BioTRIZ in projects in design, architecture and technology was evidenced. In addition, it was noted that the principles of innovation derived from biological systems tend to provide more numerous and creative contributions in terms of generating alternatives. It is also worth mentioning that BioTRIZ is more adaptable to ecological and sustainable practices compared to the TRIZ tool. Furthermore, when adopting aspects of biomimicry in their repertoire, professionals integrate natural knowledge that demonstrate potential to propagate innovative projects based on the conservation of biodiversity and that can also stimulate quality of life. It is suggested to analyze and experiment with the BioTRIZ tool in new project contexts.

Keywords: Biomimicry, BioTRIZ, Design, Sustainability, Bioinspiration

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Introduction

Biomimicry integrates knowledge from the biological sciences to generate innovations in various fields. For Benyus (1997), it corresponds to the emulation of nature and considers the biosphere as a model, measure and mentor for technologies aimed at the elaboration of products, systems and processes, also enabling the improvement of pre-existing creations. Notably in design, resources from biomimicry have been applied to establish analogies and abstractions of forms, processes, behaviors and ecosystems in many projects for our society.

In fact, in the creative domain, it is essential to implement tools and methods that assist in materializing results and proposing solutions to the challenges faced in projects, expanding the scenarios of abstraction, immersion and experimentation. In this sense, biomimicry also represents an approach that allows for sustainable proposals, since, at a more complex and systemic level, suggests adjustments in the production cycles, in order to meet the basic principles of the natural environment (Baumeister et al., 2014; Stickdorn &, Schneider, 2012).

However, it should be noted that as this is a growing and expanding area - especially regarding the consolidation of its methods and tools - some resources provided by biomimicry are still being tested and explored. Among them, it is possible to mention: Biomimicry Design Lens; Life's Principles Matrix; AskNature platform; Design by Analogy to Nature Engine platform, GEMS of SAPPhIRE req sol; and the heuristic matrix called BioTRIZ, which will be the focus of this research (Abdala et al., 2017; Ask Nature Team, 2016; Baumeister et al., 2014; DANE, 2021; Srinivasan et al., 2011).

It is worth explaining that BioTRIZ is a resource derived from the Theory for Resolution of Inventive Problems (TRIZ matrix), developed by Altshuller, that allows the transfer of solutions and knowledge from one area to another where similarities are identified (Cunha, 2015; Vincent et al., 2006).

Essentially, it is a contradiction matrix proposed by Vincent et al. (2006), which allows to recognize and resolve conflicts between parameters of a system in order to create a new design proposal. It combines processes for the abstraction of biological information. In other words, the challenges of a design are outlined by the opposition of pairs of contrasting characteristics that appear in the six organizing axes of the matrix: time, space, structure, substance, information and energy. In total, BioTRIZ covers 500 biological phenomena, with more than 270 functions, which allows the investigation of approximately 2,500 contradictions. An additional quality of this tool is its relative ease of use in teams that are not endowed with individuals with extensive biological knowledge (Srinivasan et al., 2011).

According to Craig et al. (2008), based on studies using BioTRIZ, when comparing human and natural processes, it is possible to observe that humanity prioritizes energetic factors in its technological creations, while the natural world mainly uses the domains of information and structure.

Considering the aforementioned assumptions, a survey of the specialized literature on the use of BioTRIZ in creative projects was carried out.

Method

The bibliographic search was conducted on 10/11/2020 using the descriptor 'BioTRIZ' in three databases: Web of Science, Scopus and Google Scholar. The temporal scope was not determined, therefore, corresponding to the period of the oldest publication identified in the databases until the most recent contributions found. Consequently, the period obtained for this research was equivalent to the interval between 2008 and 2020. No other exclusion criterion was used for Web of Science or Scopus. With regard to Google Scholar, only works in Portuguese that studied, analyzed or applied the BioTRIZ tool were selected.

The following categories of publication were admitted in this survey: articles, master's thesis and proceedings papers. With the aid of the VOSviewer software, the data obtained were submitted to co-citation and co-occurrence analyses. To build the word clouds, the TagCrowd platform was used.

It is important to clarify that the keyword-focused investigations aimed at highlighting the terms cited together by frequency and thematic grouping. The citation analysis intended to verify the most prominent works, and the co-citation revealed the contributions that were cited together, thus presenting an overview of the literature and the essential contributions.

Results and Discussion

Table 1 shows the data extracted from each of the databases, organizing it into general categories.

Categories	Web of Science	Scopus	Google Scholar
Works	(n = 6)	(n = 8)	(n = 4)
Countries	USA (n = 3) All other countries (n = 1)	USA (n = 3) All other countries (n = 1)	Only Brazilian works
Authors	Linsey; McAdams; Tsenn (n = 3) All other authors (n = 1)	Linsey; Tsenn (n = 3) Glier; McAdams (n = 2) All other authors (n = 1)	Camargo; Cunha; Neves; Boelter (n = 1)
Institutions	Texas A&M Univ. (n = 3) All other institutions (n = 1)	Texas A&M Univ. (n = 3) All other institutions (n = 1)	Fed. Univ. of Paraíba Federal Univ. of SC Fed. Univ. of São Carlos Pontif. Cath. Univ. of SP (n = 1)
Journals	J. of Bionic Eng.; J. of Eng., Design and Tech.; J. of Mech. Design; Int. Design Eng. Tech.; Proc. of the ASME Int. Design Eng. Tech.; Proc.of the ASME Int. Mech. Eng. (n = 1)	J. of Bionic Eng. (n = 2) All other journals (n = 1)	Fed. Univ. of Paraíba Federal Univ. of SC Fed. Univ. of São Carlos Pontif. Cath. Univ. of SP (n = 1)

Table 1: Comparisons between databases.

There is a prominence of the United States in research and projects that adopt the BioTRIZ tool. It is also noted that there is a concentration of publications by author,

since Linsey, McAdams and Tsenn are highlighted, and they share authorship in 3 articles. In Brazil, all four authors are linked to a single publication each. These results corroborate the comment, made in the Introduction, that biomimicry is an expanding area of study and the use of tools such as BioTRIZ can be further explored in creative projects.

Institutions located in the United States were more representative in the survey carried out on the Web of Science and Scopus. In Google Scholar, there is a clear highlight of public universities.

In Brazil, all publications consist of master's thesis in Google Scholar. However, it is worth mentioning that in the two other databases there is a work conducted by a team of researchers from the Federal University of Santa Catarina (Brazil) and of the RWTH Aachen University (Germany), published in the ASME Journal of Mechanical Design (Abdala et al., 2017). This article, entitled "Creative Contributions of the Methods of Inventive Principles of TRIZ and BioTRIZ to Problem Solving" investigated the stimulation of creativity in the design practice through a comparative analysis of the TRIZ and BioTRIZ tools.

Analyzing the articles identified in both researched international bases, there is a predominance of journals associated with bionic engineering, design and technology.

Figure 1 shows the word clouds elaborated with the keywords of the 18 works found since 2008. When examining the illustration, it is possible to verify that the words with the highest frequency of citation in the Web of Science were: 'design' (*n* = 65), 'methods' (*n* = 32) and 'bioinspired' (*n* = 15). Regarding Scopus, the main words were: 'design' (n = *16*), 'method / methods' (n = 9), 'model', 'problem' and 'solving' (*n* = 4). In Google Scholar, the prominent terms were: 'design' (*n* = 12); 'innovation', 'generate' and 'method' (n = 9); 'planning' and 'products' (*n* = 8). When grouping these words, it is possible to highlight the use of BioTRIZ as a method to generate ideas to solve problems and develop innovative, bioinspired and sustainable products.

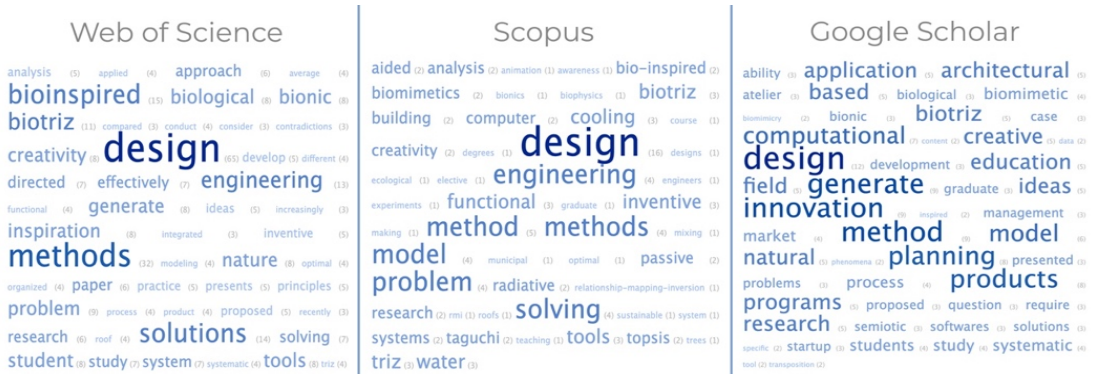

Figure 1: Word clouds created with keywords from the three databases.

Table 2 presents the works found through the Web of Science, according to authorship, title and number of citations.

Authorship and Title	Citations
Craig et. al. (2008) BioTRIZ suggests radiative cooling of buildings can be done passively by changing the structure of roof insulation to let longwave infrared pass	29
Huang, Siao (2016) Development of an integrated bionic design system	7
Abdala et al. (2017) Creative contributions of the methods of inventive principles of TRIZ and BioTRIZ to problem solving	5
Glier et al. (2011) Methods for supporting bioinspired design	4
Glier et al. (2012) Evaluating the directed method for bioinspired design	1
Durand, et al. (2015) Teaching students to innovate: evaluating methods for bioinspired design and their impact on design self-efficacy	0

Table 2: Articles with the highest number of citations in Web of Science.

This specific survey showed that the main research initiatives consist of an analysis of tools applicable in the stages of observation, assessment and conceptual design. From reading articles that addressed the matrices TRIZ and BioTRIZ, a complementarity of the functional perspective of the first, and the emphasis on biological and sustainable aspects, related to the second was observed, which justifies the use of both during projects (Abdala et al., 2017; Glier et al., 2011; Huang & Siao, 2016). It is worth mentioning that these works studied other pertinent resources for bioinspired design creations, such as: direct method approach, functional modeling, case study method, keyword translation and biological analogy search tools.

In order to distinguish the main research focuses on the BioTRIZ tool, a density map was generated for the co-citation analysis. Thus, publications that have conceptual similarities are arranged in each cluster, the most relevant being located at the center (reddish and orange areas). Furthermore, the larger the size of the names of authors, the greater their relevance. It should be noted that this illustration is not limited to the works obtained in the survey, as it is a view of citations in common (see Figure 2).

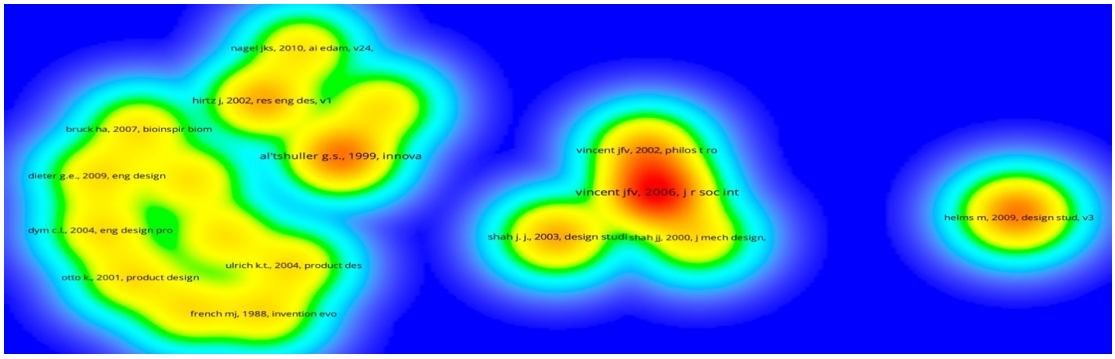

Figure 2: Co-citation map created with data from Web of Science.

When examining each cluster in Figure 2, it is observed that the nucleus concentrated around Vincent et al. (2006) comprises works with stronger convergence between them. In the article “Biomimetics: its Practice and Theory”, these authors presented the BioTRIZ tool, analyzing its advantages compared to the TRIZ matrix, originally proposed by Altshuller (1999). They warned that in the TRIZ tool there is little correspondence between biological and technological principles. Consequently, Vincent et al. (2006) aimed to supply the need for greater integration and investigation of nature in their proposal of a matrix that prioritizes structural and informational transformations, in contrast to the energy expenses – emphasized in projects based only on the TRIZ matrix. Thus, by analyzing an extensive number of biological phenomena and functions, Vincent et al. (2006) expanded and extrapolated the TRIZ matrix, creating BioTRIZ. For the authors, the insertion of biological parameters and fields favors solutions that are more adapted and harmonized with the biosphere.

On the right side of Figure 2, there is a focal point on the publication entitled “Biologically Inspired Design: Products and Processes" by Helms, Vattam and Goel (2008). The article was based on the study of bioinspired approaches in the exploration of analogies to develop solutions for products. The authors revealed that this perspective tends to produce more significant multifunctional and independent results. Helms, Vattam and Goel (2008) discussed two main approaches for bioinspired design: one focused on the problem and the other on the solution. The work also warned of common mistakes in biomimetic practices, which should be avoided during the execution of a project, such as: vague and broad definition of design challenge; inadequate combination between the design proposal and the selection of biological element; inappropriate simplification of complex biological functions and the use of pre-formulated solutions without due consideration of the context.

In the upper left corner of Figure 2, there is a grouping around the publication by Altshuller (1999): The Innovation Algorithm. This book comprises a series of essays on the development of the 40 inventive principles belonging to the TRIZ matrix. It is a work that portrays the constructive history of this tool, complemented by the thoughts and arguments of its author. Therefore, the focus of this cluster is centered on the TRIZ tool itself, which supported the creation of the BioTRIZ matrix.

Another visualization of the data from Web of Science is presented by the co-occurrence map (Figure 3), which organizes the keywords of the articles by thematic proximity groups, respectively represented by the colors red, green and blue.

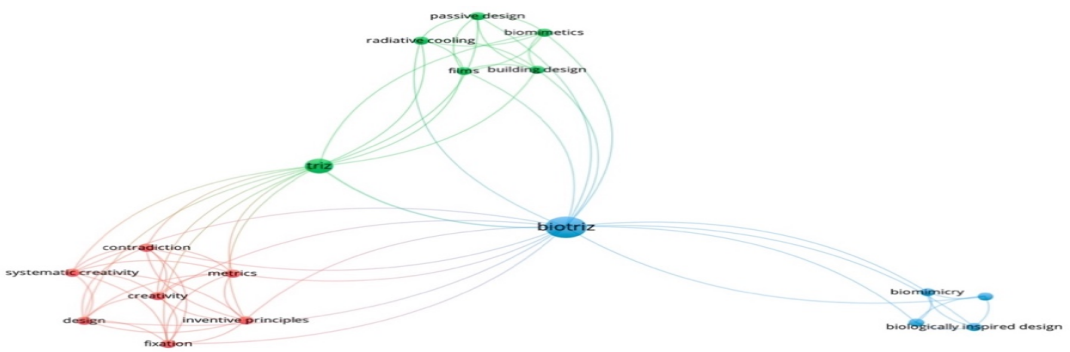

Figure 3: Co-occurrence map created with data from Web of Science.

In the image above, it is possible to perceive the existence of three clusters. In the lower right corner, words directly related to the practice of biomimicry and bioinspiration are grouped. Keywords associated with the applications of BioTRIZ are located at the top of the figure (example: effects of passive ventilation and the study of radiative cooling in buildings). On the left side (red), there is a concentration of terms related to the stimulation of creativity and the investigation of inventive principles.

Regarding the international Scopus database, Table 3 shows the articles identified in the survey and the number of citations per work.

Authorship and Title	Citations
Craig et. al. (2008) BioTRIZ suggests radiative cooling of buildings can be done passively by changing tine structure of roof insulation to let longwave infrared pass	40
Glier et al. (2011) Methods for supporting bioinspired design	11
Huang, Siao (2016) Development of an integrated bionic design system	8
Glier et al. (2012) Evaluating the directed method for bioinspired design	8
Abdala et al. (2017) Creative Contributions of the Methods of Inventive Principles of TRIZ and BioTRIZ to Problem Solving	7
Ji et al. (2013) BioTRIZ-based product innovative design process	5
Durand, et al. (2015) Teaching students to innovate: evaluating methods for bioinspired design and their impact on design self-efficacy	3
Evans-Pughe (2014) Learning from birds and bees	0

Table 3: Articles with the highest number of citations in Scopus.

Initially, it is important to mention that publications coincide with those found on the Web of Science. Considering this overlap, the authors decided to focus on the two texts that were not listed on the basis previously analyzed. Thus, the article by Ji et al. (2013) discloses a model for product design, called Relationship Mapping-Inversion (RMI), composed of two general stages: functional and technical mapping, and a phase of biological inversion. In order to observe the use of RMI, the authors applied this feature in a folding helmet design.

As for the second work, by Evans-Pughe (2014), it is interesting to note that an overview of biomimicry and related creations was presented, as well as an example of

the application of BioTRIZ for making tires for snowy regions. The benefits of renewable and sustainable approaches in biomimetic projects were also discussed, highlighting the need to metamorphose the current industrial system, especially with regard to the use of chemical additives, structures, materials and energy.

In summary, the repertoire of publications repertoire obtained with the Scopus database is associated with: a) an investigation of bioinspired methods and tools; b) case studies; c) the applications of biomimetic knowledge in products; d) the use of BioTRIZ as a teaching resource and improvement of functionality and sustainability in design scenarios; and e) an investigation of brainstorming processes.

Figure 4 illustrates the co-citation analysis and the five research clusters from 2008 to 2020.

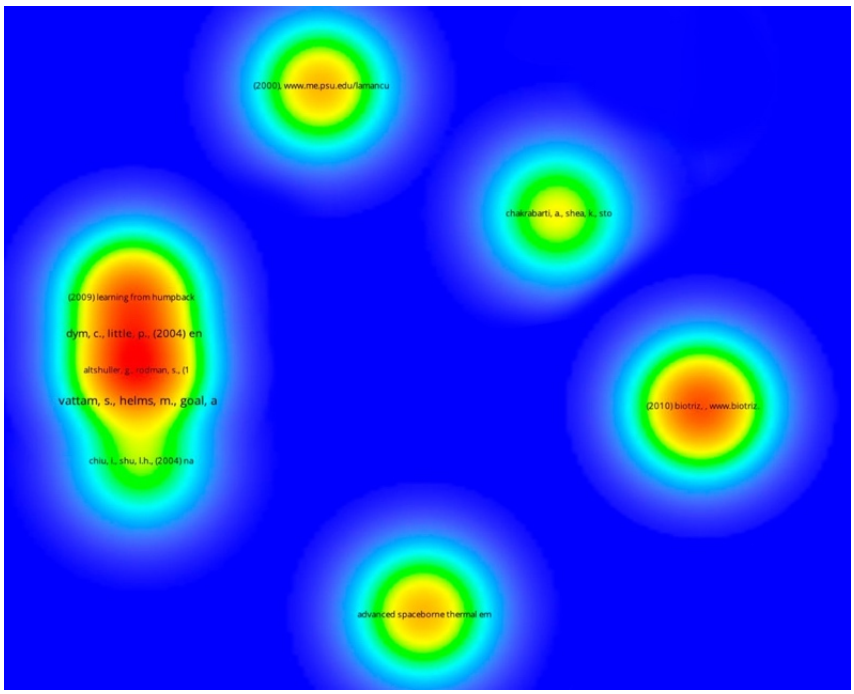

Figure 4: Co-citation map created with data from Scopus.

It is observed that the most relevant nucleus in this figure, is composed of Vattam, Helms and Goel (2008), Dym, Little and Orwin (2003) and Altshuller (1999). In "Biologically-Inspired Innovation in Engineering Design: A Cognitive Study", Vattam et al. (2008) dedicated themselves to understanding the application of biomimetic design tools in teaching and learning in design and engineering. In a course aimed at students of these areas, the authors sought to apprehend and disseminate the cognitive bases associated with bioinspired innovation. They also endeavored to develop computational tools in order to make biomimetic projects viable. According to the authors, for bioinspired innovations to be effective, it is necessary that the 'design problem' is clearly defined and it also requires an adequate degree of abstraction. Vattam et al. (2008) also consider essential to have a good understanding of the project's constraints and limits.

"Engineering Design: A Project-based Introduction" is a book by Dym, Little and Orwin (2003), which describes project management methods and conceptual design tools. Among the main issues addressed throughout the publication, the following can

be mentioned: definition of an engineering design process; establishment of objectives and required functions; generation and selection of alternatives and prototyping; design directed to use and sustainability; and ethical values involved in the production process.

Shown previously in Figure 2, generated from the search on the Web of Science, it can be observed that, in Figure 4, Altshuller's work, the "Innovation Algorithm" is now located in the most relevant cluster.

In Figure 5, the map of co-occurrences may be visualized.

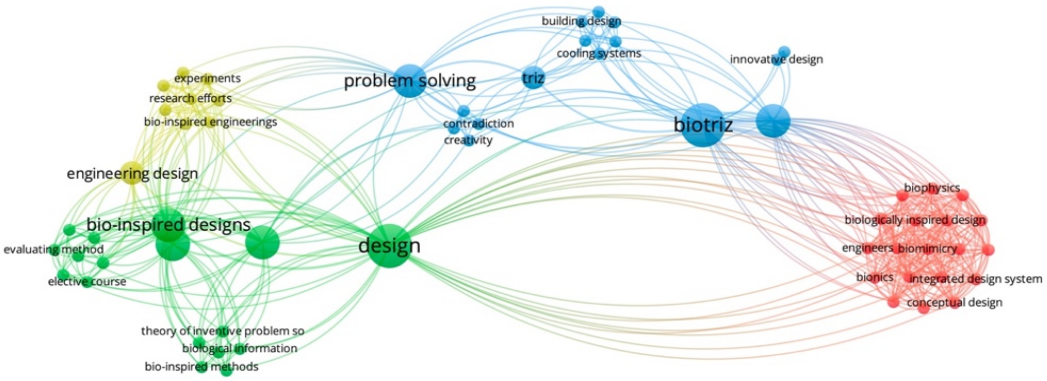

Figure 5: Co-occurrence map generated with data from Scopus.

The image shows: a concentration related to bioinspired design and the insertion of biological knowledge in creative projects (in green); a nucleus focused on experimentation and research (in yellow) and a cluster on problem solving and the development and research of technical aspects of projects (in blue). On the right side, the density of the nucleus formed by research on biomimicry, bionics and conceptual design is noteworthy (in red).

The oldest work obtained in both the Web of Science and Scopus was the article entitled "BioTRIZ Suggests Radiative Cooling of Buildings Can Be Done Passively by Changing the Structure of Roof Insulation to Let Longwave Infrared Pass" (Craig et al., 2008). This publication consists of a study on the application of BioTRIZ in a project for thermal control and environmental comfort in buildings (cooling through the incidence of infrared radiation waves and their combination with structures that promote passive ventilation) and has the highest number of citations in both databases (Table 2 and Table 3). More specifically, the work compares the matrices TRIZ, PRIZM and BioTRIZ. It was found that BioTRIZ made interesting suggestions for altering the structure of a design, unlike the other matrices that are directed towards changing the use of certain materials and finishes.

Brazilian scenario: brief considerations

Below, Table 4 lists the Brazilian production collected on the Google Scholar platform.

Authorship and Title	Citations
CEP de Camargo (2014) Semiotic transposition method for biomimetic computational modeling	1
RE Cunha (2015) Verification of the suitability of the BioTRIZ method in the application of biomimetics in the teaching of architectural design	0
JCL Neves (2015) Framework for incorporating biomimicry and product vision properties as an innovation strategy	0
NM Boelter (2018) Bionic-oriented product planning: use of bioinspirators	0

Table 4: Brazilian articles with the highest number of citations in Google Scholar.

More recent than the eight articles published in international scientific journals, the set of Brazilian works on BioTRIZ corresponds to master's thesis.

In the period stipulated for the search, only Camargo (2014) was cited (n = 1) with the work entitled “Semiotic Transposition Method for Biomimetic Computational Modeling”, in which the author presents biomimetic software for simulating biological factors in a restricted computational environment. To that end, he included biological-inspired algorithms in digital systems and also carried out a case study centered on the particularities of the species *Aplysia californica*. The model developed by Camargo (2014) operates in order to recognize and distinguish useful and non-useful information, and can be applied in other projects, especially in the context of the 'internet of things'.

The verification of publications in the Google Scholar database demonstrated that the research initiatives consist mainly of proposals on the adoption of new tools, among them the BioTRIZ matrix, in the development of products, computer systems and educational dynamics in design, architecture and technology. Other aspects investigated were: brainstorming techniques; theories of semiotics and the structural and behavioral study of organisms.
It is important to elucidate that it was not possible to build co-citation and co-occurrence maps using the VOSviewer software since Google Scholar does not provide adequate metadata for such visualizations. As for the combination of keywords in the word cloud already presented in Figure 1, it can be seen that BioTRIZ is related to the generation of innovative proposals for project management and product design.

Discussion

In summary, the bibliographic research in the three databases evidenced a general tendency to use BioTRIZ in the areas of design, sustainability, architecture and engineering. Another finding that resulted from reading the 18 identified works is that biomimicry encourages the incorporation of practices and knowledge that can stimulate the preservation of biodiversity, as well as improving the quality of life.

Furthermore, the innovation principles derived from biological systems tend to provide more numerous and creative contributions in terms of idea generation and problem solution.

The BioTRIZ tool demonstrates greater adaptability to ecological and sustainable practices compared to the TRIZ tool. One of its advantages lies in the greater variety of inventive principles and in proposing other resources for projects, such as, for example, the evidence of possibility of modifications in the structural and spatial aspects of a design.

By adopting biomimetic aspects in their repertoire of methods and tools, professionals start to integrate the vast natural knowledge that demonstrates the potential to disseminate original design proposals based on the conservation of biodiversity and that can also stimulate the quality of life, since in nature clean energy, raw material savings, non-toxic manufacturing and modularity are often valued and preferred. These are only a few of the many other factors linked to the Earth's Operating Principles, as highlighted by Baumeister et al. (2014).

Conclusion

The principles of innovation derived from the study of biological systems tend to promote more creative alternatives for projects. In addition, BioTRIZ is a tool that allows greater integration of ecological and sustainable practices and principles, compared to the TRIZ tool, which incorporates only information from patents on technological products. In summary, the BioTRIZ matrix contributes to the systematization of the use of natural elements in creative projects, facilitating the operationalization of information and biological knowledge in design (Vincent el al 2006; Helms et al., 2008).

However, as evidenced by Vattam, Helms and Goel (2008), there is still a limited understanding of bioinspiration processes in design practices. Although for hundreds of years humanity has used nature as a source of general inspiration for its creations, there is no normative or formally consolidated process that specifies the practice of biomimetic design. So, it is concluded that, as it is a recently developed resource, there is still little research on BioTRIZ. It is recommended, for future research, to carry out more experiments and case studies using this matrix in design and architecture projects in the most varied contexts.

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