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Cross-Organizational Learning Approach in the Sustainable Use of Fly Ash for Geopolymer in the Philippine Construction Industry

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Abstract: The construction industry faces a challenging situation in attaining sustainable development goals. The carbon footprint of the production and use of construction materials such as the use of ordinary Portland cement in concrete products is still on the rise despite of many alternatives and technologies. In this paper, the local cross-organizational learning approach (COLA) and a systematic review of academic and professional literatures were applied in analyzing the use of fly ash as a geopolymer in the Philippine construction industry. Three primary stakeholders were considered: academe, professional organizations, and industry. Documents from each stakeholder were collected, with keywords including sustainability, fly ash, and geopolymer. These documents included published materials, newsletters, department orders, codes, and policies. Text analytics throughout the documents were applied using the Latent Dirichlet Allocation model, which uses a hierarchal Bayesian-modelling process that groups set of items into topics to determine the maturity level of the organizational learning. An adoption framework is proposed aligning COLA with the awareness, interest, desire, and action (AIDA) funnel model. Results show that the organizational maturity until optimization of academe is sufficient towards interest and desire, while industry is highly encouraged to increase organizational maturity from managed to optimization towards desire and action. Factors such as organizational intelligence (OI) and organizational stupidity (OS) are to be considered in balancing critical thinking across organizations. Further studies are recommended by considering the use of COLA with ASEAN organizations in the development of sustainable construction materials.

Keywords: organizational learning; fly ash; geopolymer; environment; sustainable; construction

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1. Introduction

The construction industry consumes half of the non-renewable resources of the globe [1] and undoubtedly plays a major role in addressing construction material sustainability. Sustainability can be broadly defined as using resources without depletion and can be described in three spheres: social, economic, and environmental. In order to monitor protection of the current and future state of our planet, adoption of 17 Sustainable Development Goals (SDGs) and 169 targets with 232 indicators can be considered [2]. Sustainable Development Goals are difficult to achieve because of several inherent constraints, including research and development resources on a national level. Insufficient or absence of effective techniques on data knowledge management towards organizational learning should be addressed. One of the solutions is through the use of digitalization to improve the untapped role of technological innovation and knowledge management [3].

Organizational learning (OL) is gaining interest in the construction industry [4] for its added benefits, as it can be integrated to develop effective techniques in developing sustainable construction materials. It is a theory of action that constitutes a conscious and repeatable entity-wide process of creating, acquiring, understanding, sharing, applying, improving, and managing social, tacit, and explicit knowledge in support of the organization's purpose, strategies, and goals [5] and is recognized as essential for an organization's enhanced performance [6]. In addition, it is defined as the continuous increase in performance level through systematic promotion of a learning culture in an organization that includes all stakeholders of all levels as an individual and as a collective group [7]. There are two major types of knowledge that can be used in OL: explicit, as codified knowledge usually recorded in project documents; and tacit, as non-codified knowledge from personal experience that may not be recorded in project documents.

In a controlled environment wherein OL is being practiced in the organization and employee turnover rate is minimal, both explicit and tacit knowledge can be used for practice knowledge management. Explicit knowledge includes documented reports in the organization and can easily be transmitted from one person to another, while tacit knowledge is difficult to write down and difficult to transmit within an organization. One of the common tools in organizational learning in construction in extracting both types of knowledge is through post project review, by passing on previous experience to enhance organizational practices applied to future practices [8]. However, post project review is difficult to achieve if there are no available data from the organizational process assets. Tools for conducting OL, particularly aiming for good project governance, have already been developed, including those of the cross-organizational learning approach (COLA) proposed by [9]. The construction industry is highly fragmented and focused on bringing value to the client; with COLA review process, stakeholders can benefit by realizing shared objectives through sustainable business partnership [9].

The construction industry is broad, and the application of OL can be general or specific to a particular scope. Some notable works with substantial numbers of citations are on quality [10], contractor performance [11], productivity [12], building information modeling [13], and safety. Sustainable construction, in a Scopus search from 1994 to 2018, showed a rapid increase after the year 2010. One of the popular topics in this review article is on the use of alternative materials as a solution to address sustainability in construction [14]. For instance, fly ash or geopolymer material has been considered as an alternative to cement-based construction material, since its production emits less CO_2. Compared to cement, it has excellent bond strength to the concrete substrate [15] and greater durability in severe environments [16]. Geopolymer has been widely used in building materials, nuclear waste disposal, and aerospace materials [17] and is now perceived as an alternative to conventional Portland cement. In the Philippines, the use of fly ash for geopolymer has not been fully documented and its contribution as construction material has not been clearly identified. To the knowledge of the authors, there is in particular a scarcity of information related to its sustainable use in the construction industry.

This paper presents an overview on the extent of fly ash used for geopolymer as sustainable material in the Philippine construction industry. The cross-organizational learning approach [9] was adopted as tool for analyzing the state of the art regarding various stakeholders to describe the sustainability of the considered construction materials.

Information obtained from the literature, project documents, reports, memos, and other data available served as primary inputs. In addition, bibliometric analysis was performed using MATLAB to obtain text analytics. This tool shows that topic modeling for sustainability using construction demolition and waste can raise awareness in a circular economy framework [18] and development of self-healing concrete [19]. It is expected that the present paper will lead to a coherent adoption framework for the development of the sustainable use of fly ash as a geopolymer in the Philippine construction industry.

In the Philippines, coal fly ash (CFA) is one of the main raw materials for geopolymer precursors. Millions of metric tons of CFA are generated annually from the 28 coal-fired power plants currently operating throughout the Philippines. Because of its pozzolanic properties, this industrial by-product is most commonly used as a component in blended ordinary Portland cement (OPC) and marketed as eco-friendly cement products. However, for an archipelago like the Philippines, the percentage utilization of fly ash is still low [20]. For example, power plants in the cities of Naga and Toledo and even a new plant in the Visayas region have projected remaining landfill capacities in the community of less than a decade given the huge amount of CFA generated. The annual coal ash generation in the country is projected to increase to 13 million metric tons by 2035 [21].

The huge amount of CFA can be transformed into a resource for building materials through geopolymer technology. The CFA in the Philippines can be classified as Class F or Class C depending on the relative composition of the major oxides. The presence of major oxides (SiO_2 plus Al_2O_3 plus Fe_2O_3) of more than 70% suggest the pozzolanic properties of the ash, which meets the chemical requirement of Class F fly ash typically derived from bituminous coal. The fly ash also can be considered as having a moderate calcium content, which is expected for coal ash obtained from sub-bituminous coal. Such fly ash is also expected to exhibit some degree of cementitious properties typical of class C fly ash if the presence of major oxides (SiO_2 plus Al_2O_3 plus Fe_2O_3) is more than 50%.

Based on the reported diffractogram of XRD analyses of these CFA, the major components are silicon (which appeared in quartz-SiO_2), aluminum (which appeared in tricalcium aluminate and melilite), calcium (which appeared in tricalcium aluminate, lime–CaO, and melilite), and iron (which appeared in magnetite and melilite and sodium from melilite). The diffractogram did not only provide the major crystalline phase but also suggests the presence of amorphous alumina and silica. These reactive alumino–silica components are important precursors for geopolymerization.

The built environment is a major contributor to loss of biodiversity, and it is thought that raising awareness, including engaging with stakeholders, is beneficial [22]. In order to arrive at effective sustainable project delivery, a framework integrating both organizational learning and sustainability [23], and a cross-organization learning approach [9] is pursued. The motivation of this paper is to measure the research university's OL in relation to the research and development of sustainable construction materials, specifically the use of fly ash for geopolymers.

2. Methodology

Included in the COLA are the primary stakeholders from professional organizations, academe, and industry, as seen in Figure 1. There are linkages between the stakeholders, such as seminar events, which happen at least once a year with a given theme. Seminars usually caters to large audiences and pull communication is practiced. Pull communication is a method wherein a receiver proactively retrieves the information wherein tacit knowledge is limited and explicit knowledge is varying depending on the motivation of the receiver to comprehend the references available.

For the academe, De la Salle University was chosen as the subject. There were two identified research groups focusing on the development of sustainable materials using CFA, namely the Geopolymers and Advance Materials Engineering Research and Sustainability (GAMERS) and Materials for Sustainable Construction and Recyclables Applied to Projects (M-SCRAP) from chemical and civil engineering departments, respectively. The focus of the research groups is the use and sustainable consumption of CFA as supplementary cementitious material (SCM) and development of specific materials such as geopolymers. The applications range from managing coal fly ash to developing products for bricks, mortars, and concrete. In addition, a seminar-workshop on waste utilization is practiced to share results and is published with the National Library of the Philippines. This seminar-workshop covers different fields and disciplines, from chemical and material sciences to the civil engineering field, and from academe, including Japanese universities, to industry.

For the professional organizations, two associations were considered as being at the forefront of the construction industry in the Philippines. These are the Philippine Institute of Civil Engineers (PICE), composed of local and international chapters, and the Philippine Constructors Association (PCA), with different chapters locally. Regular conferences and seminars are conducted by the associations with guest experts and speakers known in their field of specialization.

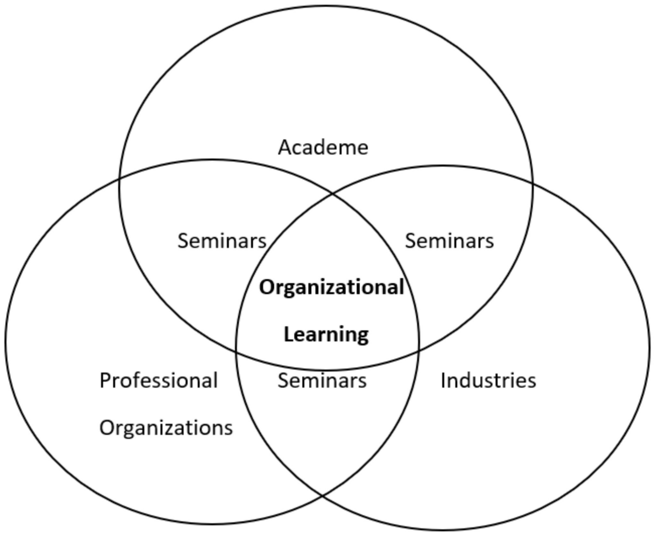

Figure 1. Cross-organizational learning approach shared across primary stakeholders.

Lastly, the Department of Public Works and Highways (DPWH) was chosen as the industry, and could also be treated as the policy maker represented in the COLA. The DPWH is mandated to undertake major infrastructure projects in the Philippines from planning to design, construction, and maintenance of national roads, bridges, flood control structures, water resources projects, and other public works. The stakeholder was chosen because of its function in providing material standards for the construction industry through one of its offices, the Bureau of Research and Standards (BRS). From the identified stakeholders, the cross-organizational learning approach was achieved to better develop an adoption framework for the research and development of the use of fly ash and geopolymers in the Philippine construction industry.

After identifying the stakeholders, data text analytics was applied using the Latent Dirichlet Allocation model that uses a hierarchical Bayesian modelling process, which groups sets of items into topics [24]. An archiving of available project documents from different stakeholders is displayed in Table 1. The documents are related to sustainable construction materials using fly ash, since this is the closest subject pertaining to geopolymers that can be gathered for both industry and professional organizations. Retrieved documents included building codes, laws/regulations/department orders, newsletters/circulars/reports, and a recent roadmap of the construction industry, 2020–2030. The documents used from academe were published documents in the form of abstracts, conferences, and journal papers with fly ash or geopolymer as the keyword. It is noted that the dates of the project documents were dispersed due to the limited documents available from each stakeholder that pertained to the keywords search used.

Additionally, a maturity level was adopted for each primary stakeholder. There are five levels of organizational maturity including initial, repeatable, defined, managed, and optimizing [25]. Three levels for measuring organizational maturity on the use of sustainable construction material with fly ash were used for simplicity in this paper. Organizational maturity was observed through text analytics, wherein frequent topics appeared in most documents. It was classified in this paper as Level 1, from initial to repeatable; Level 2, from initial to managed; and Level 3, from initial to optimizing. Progressive analysis was considered, and maturity level was established during this period.

Table 1. Primary stakeholders and documents.

Stakeholders	Description	Number of Documents	Type of Documents	Year
Academe	Utilization of Waste Seminar-Workshop	3	Book of abstracts	2013
				2018
				2019
	Engineering	45	Conference Papers Journal Papers	
Professional Organizations	Philippine Institute of Civil Engineers (PICE)	4	PD 1096	2004
			RA 544	2010
			Newsletter/Circulars	2020
			President's Report	2019
	Philippine Constructors Association (PCA)	1	Roadmap 2020–2030	2019
Industry	Department of Public Works and Highways (DPWH)	5	Research Symposium	2019
			DO 34 1991	1991
			SEM MO 2016	2016
			SEM MO 2014	2014
			Philippine Green Building Code	2015

Legend: RA—Republic Act; DO—Department Order; SEM—Social and Environmental Management Manual of Operation.

3. Results and Discussion

The documents were collected, processed, and analyzed through MATLAB text analytics. The outputs were word cloud, topic modelling, and topic mixtures. The word cloud shows the highest frequency of words in a large font. The topic modelling and mixtures show the word cloud with topics separated from a folder of documents, and the bar chart shows the probability of the topic for each document. These were used to determine the level of maturity of each stakeholder toward organizational learning using coal fly ash for geopolymer.

3.1. Academe

As seen in Table 1, the academe was separated into two parts: three seminar-workshops, and 45 published conference papers and journals. From the seminar-workshop with the theme "utilization of waste", a limited book of abstracts was available, and a word cloud was not essential in the analysis. Shown in Figure 2 is the topic modelling from the three seminar-workshops, where two topics were generated: material strength, and use of waste in concrete. It shows that the seminar-workshop covered utilization of waste in general with no specificity to the use of fly ash and or geopolymers. Shown in Figure 3 is the topic mixtures, showing that almost equal contributions from all abstracts considered both material strength and the use of waste in concrete. It is indicative from Figure 3 that waste was considered in the project documents but not much on the use of CFA towards geopolymers.

Figure 4 shows the word cloud of published materials from 45 engineering publications wherein fly ash was the main focus. Figure 5 shows the four topics generated from the documents. These were as follows: improving strength using fly ash, development of geopolymers, utilization of fly ash as additive or replacement to cement, and utilization and removal of waste. Results show that the direction of sustainable construction using fly ash is broad, including utilization of fly ash waste from industrial plants for cement replacement, development of geopolymers, and development of other materials such as mortars and bricks for a wide variety of applications.

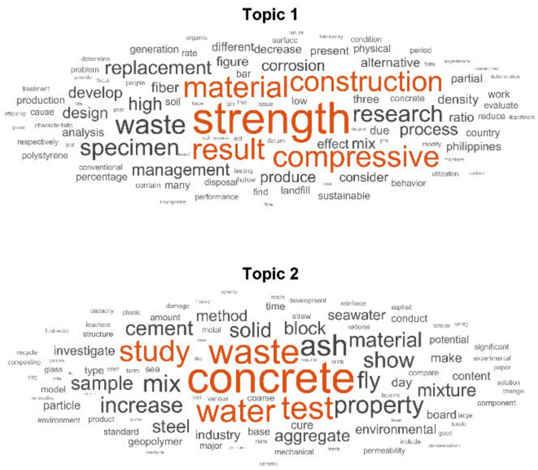

Figure 2. Topic modelling for seminar-workshop from academe.

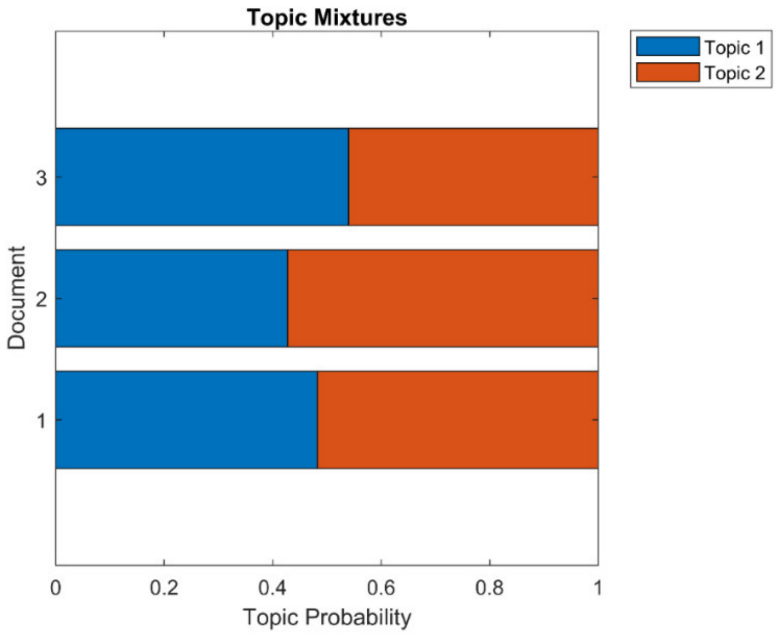

Figure 3. Topic mixtures for seminar-workshop from academe.

Figure 4. Word cloud from engineering publications from academe.

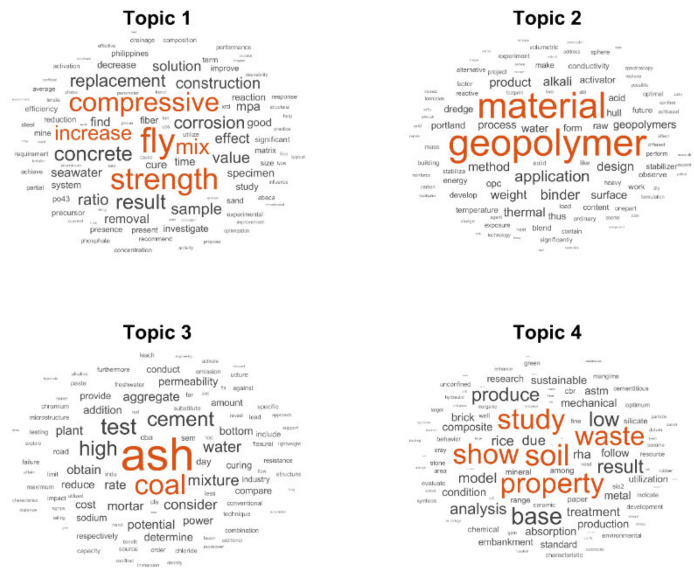

Figure 5. Topic modelling from engineering publications from academe.

Figure 6 shows the topic mixture of the 45 documents considered. For some documents, the development of geopolymers, which is topic 2 from the figure, was smaller compared to topic 3, which is using fly ash as an SCM in concrete products. It shows that the use of CFA towards geopolymers is evident. Detailed discussions on the 45 documents are described in Table 2.

The summary of work from the published materials is seen in Table 2. It shows that organizational maturity from academe was Level 3, from initial to optimizing from 2001 to present, which was the highest level. There were 16 out of 45 documents or 35.6% that studied utilization of fly ash alone or using it as an SCM in concrete products. The remaining documents, 29 out of 45 or 64.4%, explored the use of CFA for the development of geopolymers. The documents covered the use of CFA from an economic perspective; optimization of the use and design; CO_2 reduction; development of different materials including paste, mortar, bricks, soil, and concrete with ordinary Portland cement as binder; or fly ash with sodium hydroxide, sodium silicate, and other alternatives as binder. Tests differed from chemical and mechanical for the analysis of elements and compounds, compressive strength, flexural tests, permeability, and corrosion, among others.

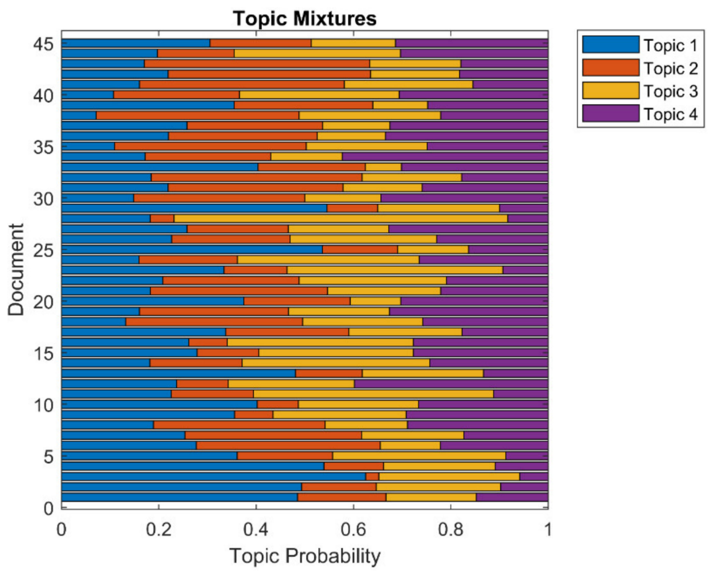

Figure 6. Topic mixtures from engineering publications from academe.

Table 2. Materials and tests from academic publications.

Reference	Materials						Test		Other Specific Tests	Remarks
	Used as		Used as Geopolymer				Chemical	Mechanical		
	CFA	SCM	M	S	B	C				
[26]	✓						✓		Leaching test	Phosphate removal
[27]		✓						✓	Corrosion test	Mortar with CFA
[28]	✓								Impact assessment	Coal ash
[29]	✓								Financial analysis	Fly and bottom ash
[30]		✓						✓		CFA and rubber crumbs
[31]		✓						✓	Corrosion test	Use of seawater
[32]			✓			✓				Optimization model
[33]						✓		✓		Fly ash and water glass solution
[34]			✓					✓		Varying sand-fly ash ratio
[35]					✓			✓	Shrinkage test	Optimization model
[20]			✓					✓		Varying sand-fly ash ratio
[36]						✓	✓	✓		Coal fly and bottom ash
[37]		✓					✓	✓		CFA, RHA, and sludge
[38]		✓						✓		CFA and ceramic waste
[39]		✓						✓		CFA/Mangima stone
[40]			✓				✓			Abaca fiber reinforced GP
[41]			✓					✓		Water treatment sludge
[42]						✓		✓		Different sizes of aggregates
[43]			✓			✓				Multi-objective optimization
[44]					✓			✓		Bottom and rice hush ash
[45]					✓		✓	✓		Gold mine tailings
[46]		✓					✓	✓		CFA and ceramic waste
[47]		✓						✓	Consolidated drain test	Road embankment
[48]				✓			✓	✓		Soil stabilizer
[49]				✓			✓	✓		Soil stabilizer
[50]				✓				✓	Leaching test	Soil and fly ash
[51]			✓				✓		Acid resistance test	Water treatment sludge

Table 2. *Cont.*

Reference	Materials						Test		Other Specific Tests	Remarks
	Used as		Used as Geopolymer				Chemical	Mechanical		
	CFA	SCM	M	S	B	C				
[52]				✓				✓	Unconfined compressive test	Silty sand embankment
[53]				✓				✓	Permeability test	Using soil mix
[54]				✓				✓	Permeability test	Using dredged soil
[55]				✓				✓		Using dredged soil
[56]				✓				✓		Using dredged soil
[57]		✓						✓	Permeability test	Pervious concrete wit CFA and sawdust
[58]	✓								CO_2 and cost evaluation	Transportation of CFA
[59]		✓					✓	✓		Autoclaved aerated
[60]			✓					✓		Self-healing using bacteri
[61]	✓				✓	✓		✓		Organic/ inorganic binders
[62]		✓						✓	Corrosion test	Use of seawater
[60]		✓						✓	Corrosion test	Use of seawater
[63]						✓			Corrosion test	GPC with reinforcement
[64]					✓			✓		Compressed earth blocks
[21]			✓				✓			Degradation of dye
[65]			✓				✓			Applied for acid treatment
[59]			✓				✓			Biomaterials for self-healing
[66]			✓				✓			Nickel-laterite as precursor

Legend: M—mortar; S—soil; B—brick/block; C—concrete; CFA—coal fly ash; SCM—supplementary cementitious material.

3.2. Professional Organizations

As seen in Table 1, a few documents were available from professional organizations. These documents were codes, newsletters, reports, and the roadmap 2020–2030. Organizational maturity was low at Level 1 from initial to repeatable. The stakeholder focused on sustainability in general and served as an ambassador to the members and the public; hence, there was not much specificity on the use of fly ash and development of geopolymers observed from text analytics.

3.3. Industry

From the documents taken from the DPWH, which is considered as the primary stakeholder for the industry, it showed that the word cloud in Figure 7 focused on environmental consideration in construction projects, which leads to the promotion of sustainability. As seen in Figure 8, the topic modelling from five documents were environmentally-friendly concrete, environmentally-friendly projects, generation of reports, and environmental impact of projects. Topic mixtures in Figure 9 were skewed differently for each topic. For example, documents 1 to 3 considered specifically the use of environmentally-friendly concrete as topic 1, while documents 4 to 5 considered in general environmentally-friendly projects with reports and impacts on the environment, which covered topic 2–4. The organizational maturity was Level 2, from initial to managed.

Figure 7. Word cloud from industry.

Figure 8. Topic modelling from industry.

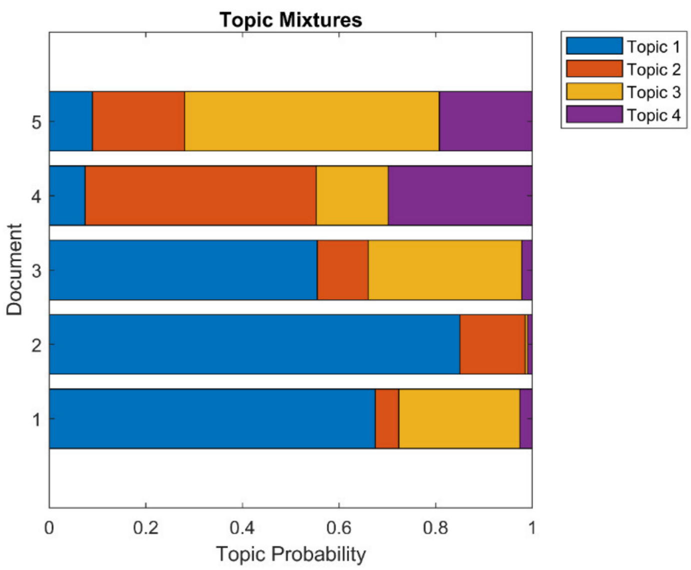

Figure 9. Topic mixtures from industry.

3.4. Cross-Organizational Learning Approach from Stakeholders

Organizational learning from academe, industry, and professional organizations was classified as Level 3, 2, and 1, respectively, based on the discussion in Sections 3.1–3.3. Academe was rated at Level 3, since published documents were managed well with room for optimization through continuous research and development. On the other hand, industry was Level 2, since the stakeholder deals with the material standards adopted by public works and highways nationwide, and professional organizations were Level 1, since while sustainability was emphasized, not much continuous development was defined. It is worth noting that the primary stakeholder from industry issued DPWH DO 23 in 1987, creating a coordinating committee for studying the application of fly ash as an admixture to concrete. After four years, another order was issued, DPWH DO 34 1991, which approved the use of fly ash that meets the requirements of ASTM C618 with 20% replacement of Portland cement in concrete mix. This shows that organizational learning towards sustainable construction materials was practiced in the industry.

Using the documents retrieved, topic modelling was generated and analyzed to align each stakeholder towards sustainability, the use of fly ash, and development of materials from the use of fly ash, such as geopolymers. Integration of COLA and an existing model, described in a later section, were considered in arriving at a proposed adoption framework.

Combining all 58 documents from Table 1 resulted in the word cloud shown in Figure 10 with fly ash in concrete materials and geopolymer development. Topic modelling is seen in Figure 11 and was categorized as follows: conducting environmentally friendly projects, utilization of fly ash in geopolymer concrete products, developing geopolymer using waste materials, and providing solutions for the construction industry. Figure 12 shows all the 58 document topic mixtures and shows varying skewness, with some documents showing prioritization on one topic over the other. For example, document 58 showed more of topic 1 (conducting environmentally friendly projects) over the use of fly ash as to whether it will be for SCM or geopolymer products. This shows that each stakeholder had different specific topics, and in general led to the development of sustainable construction materials.

After text analytics on each and consolidated knowledge from each stakeholder, a proposed adoption framework was considered. Many studies in each respective field use knowledge, competence, wisdom, talent, and learning, which are used to describe organization intelligence (OI) [67]. Opposite to OI is organizational stupidity (OS), which is considered an illnesses for organizations [68], wherein smart people pretend to be stupid [67,69] and is a concept contrary to critical thinking [70]. The OI and OS were not placed on the two extremes of a single spectrum; rather, these concepts moved hand in hand [71]. Generally, these are two counterparts, where increasing one of them leads to increases in the other.

Figure 10. Word cloud from all primary stakeholders.

Figure 11. Topic modelling from all primary stakeholders.

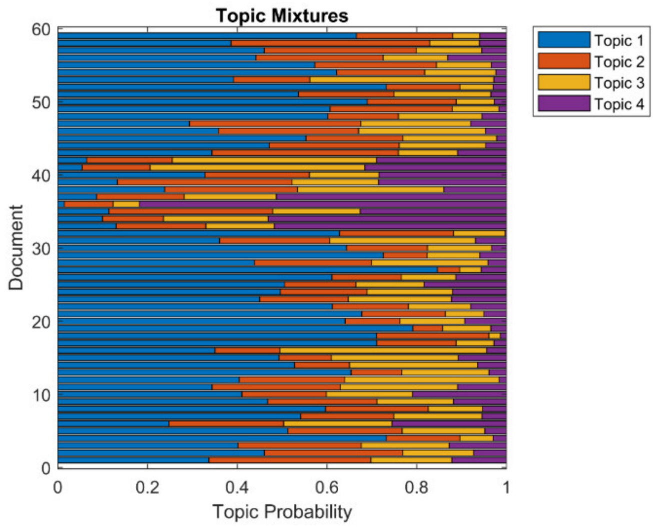

Figure 12. Topic mixtures from all primary stakeholders.

An existing model, called the awareness, interest, desire, and action (AIDA) purchase funnel model, was adopted in this paper. Integration of this model with COLA and factors such as OI and OS can lead to better understanding of an adoption framework in arriving at an OL towards sustainable construction materials. The AIDA purchase funnel model is a hierarchal diagram used for marketing wherein there is a wider opening at the top, which represents awareness, followed by narrowing down to interest, desire, and, lastly, action [72]. This model is used in marketing, where the customer journey is considered in purchasing goods or services. Figure 13 shows the COLA from the primary stakeholders and balancing its organizational maturity level, and the role that each primary stakeholder plays in the development of proper OL, where OI and OS exists in the organizations. Professional organizations with maturity from initial to repeatable is observed in the awareness and interest of using sustainable materials like fly ash and geopolymers. From the academe, the position on the funnel on awareness, interest, and desire is highly correlated with organizational maturity from initial to optimizing. On the other hand, development and motivation for industry is highly recommended, since the current maturity is from initial to managed with little or no action. This does not negate that there is no research and development on the field of CFA and other materials in the industry; in fact, from 2016 to present, numerous department orders from DPWH in relation to concrete were made, such as inclusion of macro synthetic fiber for Portland cement concrete pavement, standard specification of the use of roller-compacted concrete pavement, and use of one-day Portland cement concrete pavement, which shows that the cross-organizational learning approach is recommended to harmonize the learning process and attain sustainable development goals in the Philippine construction industry. It is recommended that interventions from new technology, market demand, legal requirements, and environmental considerations be used as motivators to move awareness to action for all stakeholders in the continuous learning process in the development of sustainable materials.

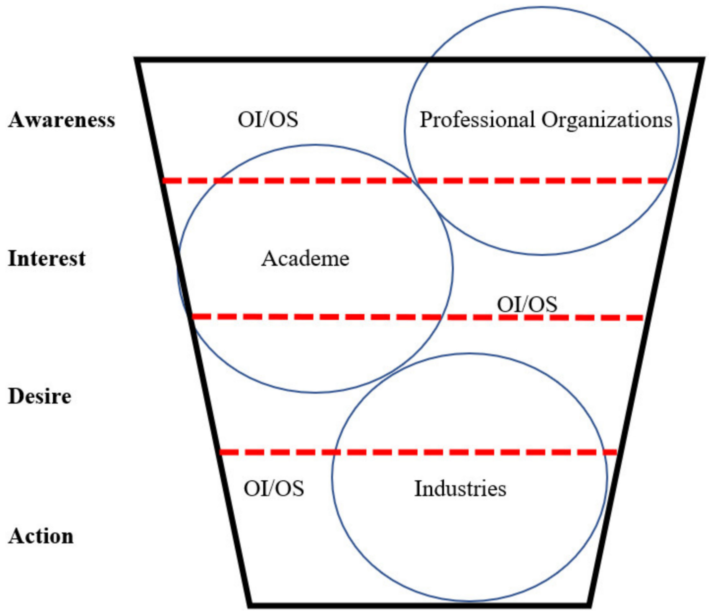

Figure 13. Primary stakeholders in the AIDA funnel model.

4. Conclusions

The construction industry has contributed substantially to CO_2 emissions compared to other sectors. The challenge of attaining sustainable development goals can be achieved with a good adoption framework, wherein different stakeholders can apply a cross-organizational learning approach (COLA). Results show that a local COLA and systematic review from academic and professional literatures using text analytics to understand explicit knowledge from documents can be achieved. Alignment of COLA's maturity level and the AIDA (awareness, interest, desire, and action) purchase funnel model can lead to an adoption framework.

It was found that the maturity of the sustainable use of fly ash for geopolymers according to the perspective of professional organizations is from initial to repeatable, as observed in the awareness and interest scale. Professional organizations can be the ambassadors for sustainable development goals wherein awareness and interest can be imparted to the members and the public. From the viewpoint of academe, the awareness of, interest in, and desire for the use of these alternative construction materials are highly correlated with organizational maturity, from initial to optimization. Academe can continue with research and development with interest and desire, considering organizational maturity until optimization. Lastly, industry, as one of the primary stakeholders, plays an important role in developing organizational maturity until optimization with desire and action in using fly ash and to develop more materials from it. It is recommended that interventions can be made, such as motivation coming from new technology, market demand, and environmental considerations. The movement from awareness to action for all stakeholders is the ideal setting in order to have a continuous learning process in the development of sustainable materials.

Further studies are recommended by considering COLA from wider organizations, locally and internationally, in developing sustainable construction materials. Benchmarking can bring about best practices on the adoption of new materials in the construction industry.

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