Organic Strategies to Sustainable Buildings and Cities

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Abstract: In the pursuit of creating sustainable buildings and cities, architectural strategies have mainly focused on approaches relying on technological efficiency and engineered systems. The focus has been such because these strategies are evolutionary in that they are solutions to the problems posed by existing building system design strategies and are thus more easily integrated into those systems. In some cases however, architectural offices have been teaming with landscape architects and other professions whose focus are more on natural systems rather than building systems. In these cases where disciplines have worked cooperatively toward the goal of sustainability, strategies have emerged which take a combined approach in which building systems utilize and integrate with natural systems. Projects and strategies that have emerged from these collaborative endeavors can provide architects and city builders with valuable lessons and insights and contribute to developing a better overall framework for approaching sustainability in the built environment. Through an examination of recent successful sustainable building projects in which architects have worked collaboratively with landscape architects, natural scientists, and similarly focused professions, this research analyzes specific strategies, methods, and construction details which integrate building systems with natural systems, providing valuable lessons for such collaborative approaches and insights for approaching sustainable buildings.

I. Introduction: Landscape in Building Design

In recent years, the term landscape has become popularized in the architecture profession. The term has crept into the jargon of many architects and builders, appearing in prominent architectural writings in reference to new building projects which include plant materials incorporated into their structures or involve the integration of buildings and earth forms. The inclusion of landscape within the structure of architecture has been used to sometimes connotate a measure of environmental awareness or a closer relationship with the earth. In some cases, such uses of landscape in architecture have been deceiving or as ambiguous as the use of "green." Despite this ambiguity, the interest by architects in incorporating nature into their buildings through the use of landscape can have positive implications for sustainability. It has led many architects to seek out cooperative efforts with landscape architects, environmental scientists, and other environment related professions as collaborators and consultants in their designs. This collaboration has the potential to serve as a catalyst for the reevaluation of current sustainable design strategies which often rely heavily on technological solutions. It may also serve to bring about a reinterpretation of the built environment's relationship to the natural environment. This in turn can lead to the development of buildings and cities which are more cooperative with natural systems, are better able to adapt to changing conditions, enrich their local ecology, and strengthen connections between people and natural processes.

II. Approaches to Sustainable Building Design: Technologically Driven versus Integrative

Modern buildings are sophisticated systems which incorporate a variety of technological subsystems to maintain conditions suitable for human uses. In large part, sustainable design, as it relates to architecture, has been the mitigation of the environmental impacts caused by the construction and operations of building systems. In the pursuit of this, many building projects focus on strategies and methods that utilize technological improvements in the operations of the building to gain efficiencies in order to reduce their negative environmental impacts. They employ such strategies as: new technological insulation materials and double-skin facades for building envelopes; light shelves, shading devices, and energy efficient bulbs for lighting; solar systems and cooling towers for heat gain and cooling; photovoltaic's and wind turbines for energy needs; or phase change materials and filters for waste water treatment and reuse. While such strategies and methods produce significant results in the reduction of building related consumptions of energy and resources, and reductions in the generation of building related wastes and pollution, they often do not seek any contribution or part in the environment in which they reside (or displace). The focus of these strategies emphasizes an improvement in the efficiencies of building centric systems, whose basis of design is to circumvent or substitute natural systems while ignoring their biological purposes and functions. The result is that they still maintain many problems that exist with the technologically based systems in the first place. First, they are rigid with regard to their environmental adaptivity, producing systems in which a narrow range of operations and conditions must persist which may be counter to local environmental systems. Second, they only abstractly or distantly, or worse, superficially, reflect real and/or underlying ecologies. Finally, they often continue to isolate people from the natural processes, producing building systems which are not as environmentally rich or connective as they might be. Thus they do not produce changes in the relationship between people and the environment, but operate in a manner of containment of negative effects.

Rather than merely reducing negative environmental impacts, strategies might be employed which are positive in their approach, leading to systems that are flexible in their interactions with natural systems, responsive and adaptive to such changes, and comprehensible and didactic in their connections with nature. They might seek symbiotic relationships with ecologies, hydrology, and cultures where they exist. By approaching the building and its systems as part of a large but also very local environmental context, it is possible to develop environmentally sustainable buildings which are more genuinely sustainable and possess meaning as such. Such an approach might be considered landscape centric. It does not require an abandonment of technology, but it does require that technological improvement is used wisely in complement with other strategies, that it is developed in a way that will improve the connection of building systems to natural systems rather than replacing or simplifying them, and that it does not deceive people in its purposes and regarding its connections with natural systems.

In the past an overreliance on technology in the development of solutions for the built environment has created rifts between building systems and natural processes. Many architects have written critically about the relationship between architecture and nature. Architect Malcolm Wells in his book, Gentle Architecture, asks the question "Why is it that almost every architect can recognize and appreciate beauty in the natural world and yet so often fail to endow his own work with it" (1981, 41). Wells asserts that architecture has greater responsibilities to the environment than it maintains and sets up standards for a better relationship to natural systems. He expresses that buildings should consume their own waste, provide animal habitat, and moderate their own climate (1981). More than two decades later, Ken Yeang, in his essay, On Green Design, is not just critical of architecture's impact on the environment, but also its methods which may rely too much on technology for mitigating its impacts. He says:

> There is also much misperception about what is ecological design today. We must not be misled by the popular perception that if we assemble in one single building enough eco-gadgetry such as solar collectors, photo-voltaics, biological recycling systems, building automation systems and double-skin facades, we will instantaneously have an ecological architecture. The other misperception is that if our building gets a high notch in a green-rating system, then all is well. Of course, nothing could be further from the truth. Worse, a self-complacency sets in whereupon nothing further is done to improve environmental degradation. (2007, 22)

Yeang, in this quote, is also critical of building rating systems such as the LEED (Leadership in Energy and Environmental Design) Green Building Rating System in the United States. A systematic approach, the LEED program awards points based on the meeting of set criteria in the measurement of environmental sustainability. Yeang seems to doubt that systems like LEED are capable of providing a lasting change in approach or even providing the right kind of change. Rather, he feels that these programs might represent the replacement of one kind of complacency for another with an overreliance on technology as a solution to all problems.

Although Yeang is critical of building rating systems, they may be part of a long term solution. Such systems provide a method of measurement which clarifies standards and allows for clarity in evaluations and comparisons of sustainable buildings. Furthermore, LEED in particular has been able to produce a greater number of cooperative efforts in sustainable building projects through its encouragement of collaboration among disciplines. The US Green Building Council (USGBC), the developer of LEED, through its literature promotes its program as a "whole building approach" which encourages architects to work cooperatively with other design disciplines by considering design more holistically. This is meant to encourage builders and architects to consider multiple building systems and their synergies in the achievement of sustainability goals, rather than focusing on isolated system goals. It also provides additional mechanisms in its process to encourage cooperation through delegation of authority among various design professions and by promoting collaboration in the administration of a project. This has created opportunities in which the viewpoints of various design professionals have new influence in the design process for buildings, leading to new and innovative approaches to sustainable building design. In conjunction with interests in landscape centric approaches and sustainability, such cooperative efforts have led to the development of some innovative projects and methods which may provide architects and other design professionals with insights regarding a greater integration of building systems and natural ones. By examining these projects in their uses of technological solutions and the extent to which they utilize integrative strategies, the value of such collaborative efforts with regard to sustainable building practices can be evaluated.

III. Projects:

California Academy of Sciences, San Francisco, California, U.S.A.

Some notable building projects exist which utilize strategies that can provide insights into the efficacy of collaborative efforts between architects and natural system linked design professionals and their value with regard to the integration of building systems and natural systems. One such cooperative effort is the recently built and award winning California Academy of Sciences museum in San Francisco's Golden Gate Park (Fig.1). The project was developed as a replacement for the Academy's previous cluster of buildings in the same location which were damaged in the 1989 earthquake affecting San Francisco. The project team included lead designer, Renzo Piano Building Workshop, Chong Partners (now Stantec Architecture), landscape architects SWA Group, and biological consultant Rana Creek.

Figure 1: The new building of the California Academy of Sciences. (Courtesy of Earth2tech)

The project was awarded a LEED Platinum certification – (LEED's highest award), for its design and construction by using strategies such as; the use of recycled materials (Over 90% of the demolition waste from the old academy was recycled), natural lighting (at least 90 percent of regularly occupied spaces have access to daylight) (Stone 2008), natural ventilation (about 40 percent of the academy utilizes natural ventilation), a perimeter canopy of photovoltaic cells (providing at least 5 percent of the building's power) (Steen 2008), and a gray-water collection system (Post 2008), However, the most significant component of the building's design, and its most significant with regard to developing a relationship between building and natural systems, is its green roof.

Figure 2: The front view of California Academy of Sciences showing the undulating roof against hills in San Francisco (Courtesy of California Academy of Sciences)

The roof is designed as an undulating blanket laid over the top of the building structure with the spherical forms of a planetarium and a rainforest terrarium pushing up surface of the roof plane from the interior of the building below to form two large mounds that along with 5 smaller mounds are meant to evoke the 7 hills of the city of San Francisco's landscape (Fig. 2). The undulating hills of the roof make it visible from the ground level which overcomes a problem many green roofs have of being seen. The roof is 2.5 acres and is planted with 1.7 million plants of nine native species. It is meant that the roof serves as a wildlife habitat that will attract pollinating animals, like hummingbirds, bumble-bees and butterflies (Steen 2008). The plants used for the roof were chosen for their adaptability to the Bay Area's seasonal rainfall cycle (SWA 2008). For San Francisco, the green roof creates the most concentrated area of native wildflowers within the city (Green Roofs for Healthy Cities 2008). The roof is also an educative component of the building, which is partially accessible and is integrated into the program of the museum.

The concept of the roof developed from Renzo Piano's idea for creating the building as a continuity of the park. Describing his concept he said, "The idea was to cut a piece of the park, push it up 35 feet - to the height of the old buildings - and then put whatever was needed underneath" (Steen 2008). Though the development of the roof as a diverse habitat might seem integral to the design, it was not a straightforward process. In his vision for the roof Renzo Piano preferred a plant palette that was monolithic, neat, and clean (Steen 2008). He was originally dissatisfied by the plants presented to him by botanists for the roof which were not necessarily chosen for their beauty, but for their ecological value. However, consultants of Rana Creek, along with the landscape architects of SWA, through experimentation, found plants which were able to satisfy Piano's aesthetics and achieve the diversity desired. These differences of view in plant aesthetics attests to the value that collaboration brought to the design process.

In addition to providing habitat for plant and animal species, the roof also tries to maintain a connection with local hydrology. Most of the rain water falling onto the roof is captured for the irrigation needs of the roof's plant materials in panelized reservoirs along the roof's surface underneath the plant materials and their growing medium. The water quantities exceeding irrigation needs are siphoned off the roof by a crisscrossing system of gabions to an underground water table recharge system (Fig. 3). Filtered through sand and gravel, the rainwater in the chamber naturally percolates back into the water table of Golden Gate Park.

Beyond its connections to natural systems, the green roof serves as an important component of the operational systems of the building. The steep slopes of the roof mounds create a natural ventilation and cooling system which reduces the use of mechanical cooling. Outdoor air cooled by the vegetated roof surface is funneled into the entry plaza whose mechanically operable skylights open to allow the cooled air to flow into the building interior. The roof also helps to regulate indoor temperatures by creating a thermal buffer for the spaces below. The seven inches of soil substrate on the roof, acting as natural insulation, are expected to maintain the building's interior an average of 10 degrees cooler than a standard roof would in hot weather (Stone 2007).

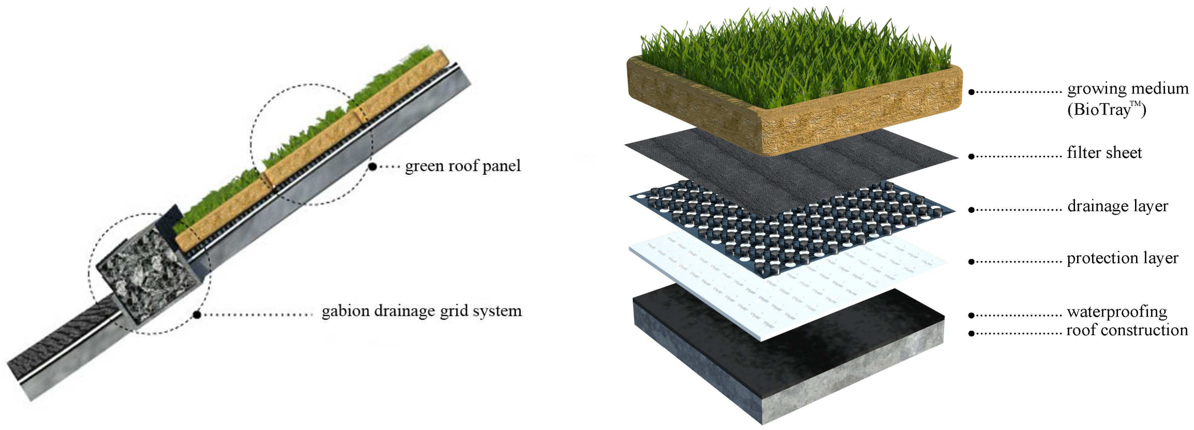

Figure 3: Green roof system drainage components (left) & panel composition (right) (drawn by: Alejandro Stein)

Despite the naturalized appearance and use of natural processes, the design of the California Academy of Sciences green roof employs a great deal of engineering to make it function. Overall, the building utilizes large amounts of technology and gadgetry as components of its sustainable design strategies. The green roof provides an interface between the technologically sophisticated building and the world outside (nature). Through its habitat function and its attention to site hydrology, the roof establishes a connection with natural systems which is positive and contributory. Its visibility and access as a museum exhibit also promote connections between building users and nature. The connection between the functions of the green roof and building HVAC systems and electricity usage illustrates a symbiotic relationship between the building and natural systems. One shortcoming of the design is that access to the entire roof is limited to an observation area at one corner of the building roof. A stronger interaction between the roof and the building occupants would improve the value of the design. With regard to adaptability and responsiveness to changing conditions in natural systems, the roof has exhibited some adaptability according to botanists working for the academy. Birds and bees have deposited foreign pollens and seeds on the site, bringing new species of plants (Steen 2008). Depending on how these species interact with the existing roof habitat, they are allowed to remain or are removed by maintenance workers. Such flexibility may seem minimal, but it is an important step forward and demonstrates how flexibility in a building system might work.

Sidwell Friends School, Washington, District of Columbia, U.S.A.

Going a step further in linking people and buildings to natural systems is the Sidwell Friends School (Fig. 4) in Washington D.C. designed by Kieran Timberlake Architects with Andropogon Landscape Architects and consultants Natural Systems International. Sidwell is a school founded on the Quaker philosophy of human beings as stewards of the Earth. The school, during an expansion in 2007, wanted to strengthen the link between this philosophy and the curriculum by integrating it into the design of its facilities. The project, like the California Academy of Sciences museum building, received LEED Platinum certification. The project's environmental credentials are numerous with strategies that include light shelves, a green roof, operable skylights, reuse of an existing building stock, use of recycled content in the building's construction, use of solar chimneys for passive cooling, and use of photovoltaic cells for electricity. These strategies have reduced energy demand by 60% when compared to other similar sized schools (AIA 2007). The centerpiece of the project's design, and its strongest link between natural processes and the building, is the school's courtyard which contains terraced wetlands and a rain garden for the reuse and recycling of water (Chen 2007).
The wetlands, in combination with a biological filtering system, are used to process and treat wastewater created by the school for reuse in the school's toilets and its cooling towers, and also for infiltration. The process begins with a primary treatment of wastewater in an underground tank. The water is then circulated through a series of reed bed in the school's courtyard. Within the wetland, microorganisms attached to gravel in the planting medium, in conjunction with the roots of the plants, breakdown contaminants in the water. Trickle and sand filters provide further treatment (Fig. 5). The system receives up to 3000 gallons of wastewater per day (Margolis & Robinson 2007). During the winter time warm wastewater entering the system prevents the wetlands from freezing making the system viable year round.

Figure 4: Sidwell Friends School, building and constructed wetlands (Courtesy of Green Infrastructure)

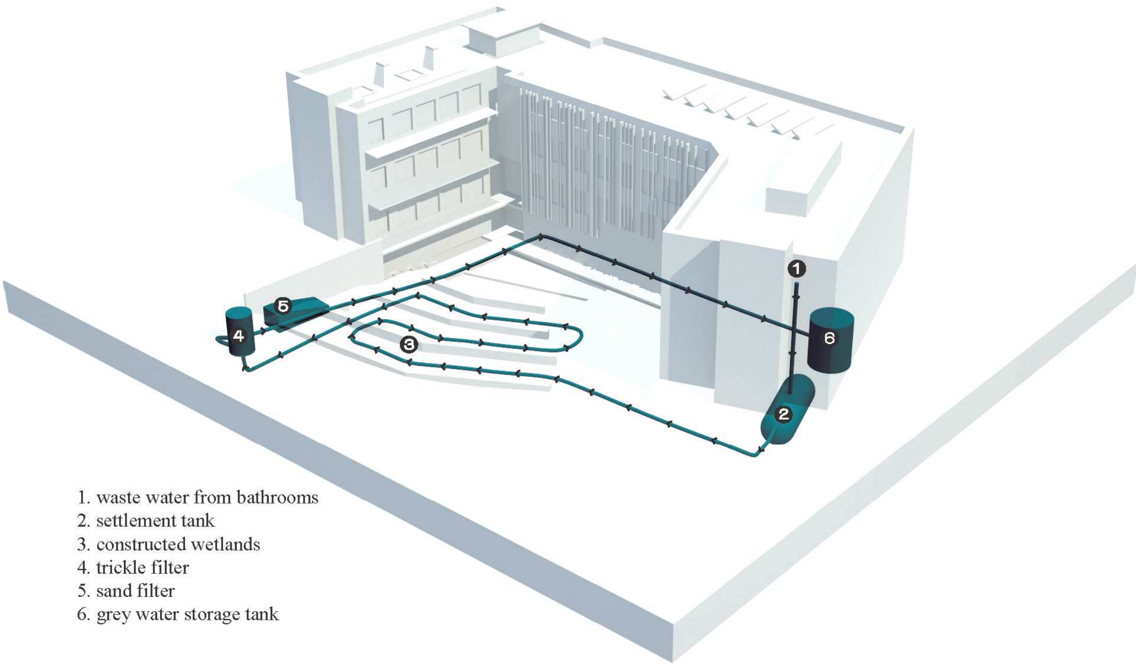

Figure 5: Wastewater treatment wetland system, Sidwell Friends School (drawn by: Alejandro Stein)

Overall, the system achieves water savings of 90% (Tutterow, & Filippov & Harris 2008). Additionally, using biological processes to treat wastewater is energy efficient and produces significantly less sludge waste than conventional processes. In addition to water and energy savings and the reduction in generated waste material, the terraced wetlands have created habitat for local insects, birds and small animals. It uses planting design that follows the range of plant communities that would occur along the soil within each given moisture gradient to create habitats reflective of what might naturally exist on the site. Using native plant species is a strategy that extends throughout the school grounds, strengthening connections between local ecology and the school.

In addition to treating wastewater through its wetlands, the school also captures rainwater from its roof to aid in its irrigation needs and for use within the courtyard to supply a biological education pond. During seasons of high precipitation, water directly supplies the needs of the pond. Excess rainwater is stored in an underground cistern which is then used to supply the pond during dry seasons when its levels are low (Fig. 6).

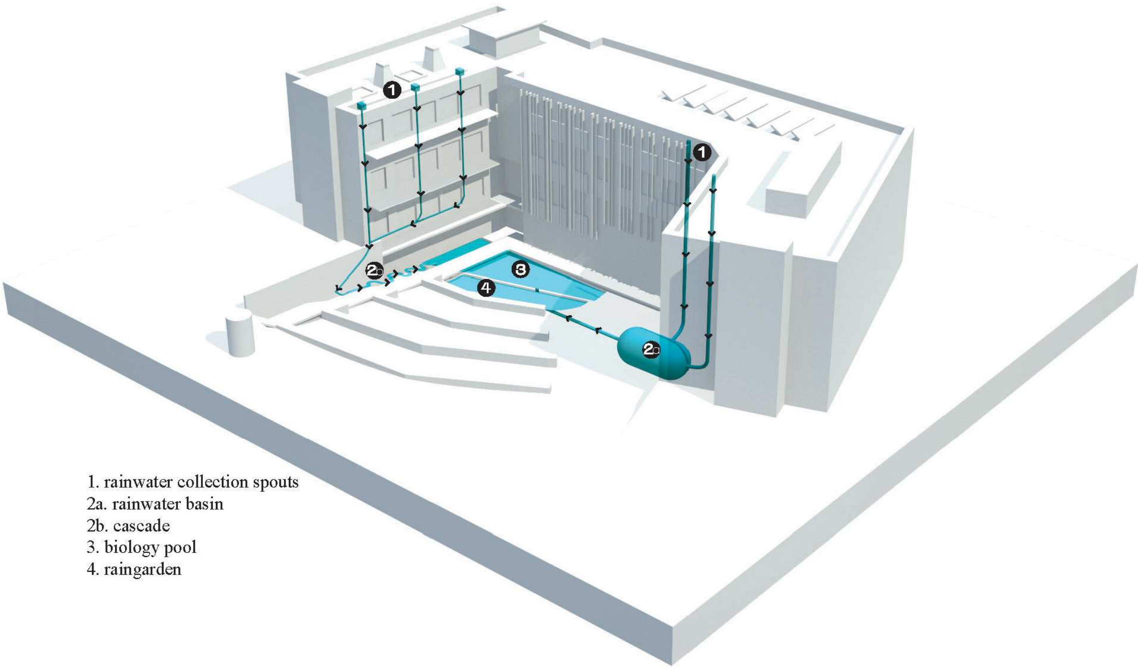

Figure 6: Rainwater capture and biology pond, Sidwell Friends School (drawn by: Alejandro Stein)

The treatment of the school grounds is an integral component of a larger strategy within the school to foster connections between the students and their environment, both inside and outside the school. Learning about the building and its systems, and its connections to natural processes, is part of the educational curriculum. The goal is to make systems and their processes evident. Students have access to monitors which measure such things as the temperature outside and inside the building, air quality, wind speeds, rainfall levels, and the health of their school's wetlands. The blending of the school's water supply and wastewater treatment systems with natural processes in the wetland systems sit at the center of a design which works to provide a strong connection between the building and natural processes, the building and the people inside, and also between people and natural processes.

The school's green roof, although very limited in comparison to the one on the California Academy also contributes to the connections between the building and its landscape. Additionally, the green roof of Sidwell also functions as a rooftop vegetable and herb garden where students grow some of the food which is used in the school's cafeteria, developing another connection between students and natural processes.

Overall, the Sidwell Friends School represents a notable example for the integration of landscape and building systems. It provides connections between building functions and natural ones in many ways, most notably with its integration of building wastewater treatment and water use with hydrological and wetland systems. This project does very well connecting people, building systems, and natural systems. The integration of building and natural systems appears comprehensible and is didactic. The wetland system expresses flexibility in its operations with its ability to adjust to cold weather and the biological pond also expresses similar flexibility in its adjustments to wet and dry seasonal changes. Although the project is mostly a successful one, some shortcomings exist. Hiding the primary treatment process facilities underground may be a somewhat questionable element in the project in that it seems deceptive in illustrating the water treatment process, possibly giving the perception that it functions independently of additional technology. Additionally, the adjacencies of the wastewater treatment system, the stormwater collection system, and the biological pond also seem to imply a connection that does not really exist. Information regarding these items is not hidden in literature about the project or in instruction to students, but the system could have been developed with greater clarity. Although these shortcomings hurt the project somewhat, as a whole the project seems to use technology positively to further connections between people and natural processes. It also represents a successful collaboration linking building systems and natural systems.

IV. Conclusion

With the increasing urgency of finding sustainable answers to the world's problems, solutions are necessary which do not just depend on mitigation through efficiency, but include the development of new connections and symbioses between human systems and ecological ones. In his article entitled "Making the Case for Landscape Ecology," ecologist Jianguo Wu, contrasts modern human engineering systems with those of beavers (2008). In so doing he articulates that human beings must find an alternative way of building their environment. Drawing upon the concept of human beings as "ecosystem engineers" that actively develop and maintain their own habitat, Wu notes that beavers are also engineers of their own ecosystem, utilizing trees to build dams as habitation for themselves. "However, even if beavers change a natural landscape from one state to another, their influences are usually confined within the local landscape" (Wu 2008, 47). Furthermore, as beavers do alter their systems, they do not replace them with simplified, ecologically inefficient versions as humans often do or alter their environments at the scales that humans do. Human beings may not be able to live as beavers, but this illustrates the profound problems that current human systems maintain in their relationship with natural systems. Improving this relationship requires a reevaluation of it as it now exists.

Architects and builders, who seek a path to sustainability in their work, should look beyond solutions to existing systems. By depending solely on strategies of containment and increased efficiencies, opportunities to develop better systems may be overlooked and left out. Strategies need to focus on developing new systems which are compatible with natural systems and processes. This requires a landscape centric (integrative) mindset rather than a building centric (technologic) one. Through collaborative efforts with other professionals with knowledge of natural processes, and with an increased understanding of the relationship between the human environment and the natural one, architects and builders can move toward a new paradigm in which buildings and cities look to natural systems for an example and a partner.

Acknowledgements

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Reuse of Waste Marble Dust in the Landfill Layer

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Abstract: Waste materials are serious environmental problem because they have harmed to soil and ground water. Rapidly developing technology has increased production and consumption. The increasing of production and consumption results in the increase of amount of waste. In the developing countries, distinct rules of waste disposing are initiated to prevent the environment pollution. This case was positive effects on environment by means of recycling, regains to economy and reducing environmental pollutions. Recently, some waste materials were began to be used with clay in landfill layer design. Because the waste materials increases characteristic of clay liner such as impermeability, strength, heavy metal absorption, etc. In this study, waste marble dust was used as an additive material in landfill liner. Mixtures of kaolinite-bentonite were mixed with waste marble dust for design of landfill liner. This process was performed at marble dust ratio of 5%, 10% and 15%. Freezing-thawing tests were carried out in these mixtures. At the end of the tests, it was observed that waste marble dust increased strength of liner in conditions of freezing and thawing.

Keywords: Waste marble dust, Environment, landfill liner, freezing-thawing

1. Introduction

The waste materials are serious environmental problem. Rapidly growing cities with increasing population have formed this problem. Concentration of population in cities has increased consumption. The increasing of production and consumption results in the increase of amount of waste. In the developing countries, distinct rules of waste disposing are initiated to prevent the environment pollution. However, many technologies are developed for the recycling of wastes; many of them cannot be recycled by the economical and technological points of view. The collected wastes can be burned and/or composted by newly developed technologies; however, a final amount of trashes must be stored for the last removal procedure.

In the landfill layers, usage of suitable materials and possibly waste mixture material are important to prevent from environmental conditions. By this way, the waste materials, such as fly ash, would be gained to economy.

In recent times, waste marble dust was used as an additive material for soil stabilization. Okagbue and Onyeobi's study (1999) showed that the geotechnical parameters of red tropical soils are improved substantially by the addition of marble dust, plasticity was reduced by 20 to 33% and strength and CBR increased by 30 to 46% and 27 to 55% respectively. Additionally, normal 28 day curing improved after 7 to 10 days of normal curing.

The effect of waste marble dust on swelling potential of Na-bentonite and Meşelik clays was investigated by Zorluer (2003). Specimens were mixed with marble dust at different percentages of dry soil weight. Then, they were compacted at the standard compaction effort and swelling tests were carried out with odometer apparatus. The experimental results reveal that waste marble dust is effective for controlling of swelling potential and it can be used for this purpose.

Also marble dust affect unconfined compression strength of clay soils according to study of Zorluer (2006). Clay soil had mixed marble dust at 3, 5, 8, 10 % percentages. Then mixtures had been compacted with standard proctor compaction energy. Specimens had been sampled from compacted soils for compression test. At the end of 28 days curing time, strength increased 20.1 by N/cm^2 to 57.3 N/cm^2.

Hassini (1992) determined that impermeable layer cycles much at landfills. In doing so, he carried out an experiment of freezing-thawing to specify soil strength and its permeability. After 12 cycles, as suggested by

Chamberlain (1981), he found that 10-15% grain loss does not have any impact on strength.

This study examines the degree of deformation derived from seasonal temperature differences at impermeable layers with marble dust. For this reason, three mixture of soil to waste marble dust (the proportions were 5, 10, 15% dust to dry soil by weight) have been prepared. And freezing-thawing tests were carried out in these mixtures.

2. Materials

2.1 Na Bentonite Clay

Bentonite is a colloidal aluminium hydro silicate. The volume of bentonite can rise 10 to 30 times by the addition of water. It has a swelling characteristic till 200°C. This property loses completely over 600°C. The bentonite clay used in this study is Na-Bentonite. It was supplied from the Karakaya Bentonite factory, Ankara Turkey. Some physicochemical and geotechnical parameters of Na Bentonite clay were shown in table 1, The results of chemical analysis determined by the X-Ray Flourans Elemental analysis are shown in table 2 (Koyuncu 1998).

2.2 Kaolinite Clay

Kaolinite clay is a product of a type of rock which contains a great amount of feldspar. Kaolinite consists of silica and aluminium layers. The thickness of layers is 7.2 Å, the length of layers is between 1000 and 20000 Å and the specific surface area is (SSA) 15 m^2/g. The clay used in this study is obtained from the Bilecik district. The clay is produced by a three step procedure; first excavation from clay ores, then cleaning from fine sand by water washing and, finally crashing below 40 µm at the end of washing, groups of clay and shale are completely decomposed. The clay used consists of kaolinite mineral. Some physicochemical and geotechnical parameters of the kaolinite clay are shown in table 1, The results of chemical analysis determined by the X-Ray Flourans Elemental analysis are shown in table 2 (Koyuncu 1998).

2.3 Waste Marble Dust

Marble dust is minimum sized marble waste. It occurs with sawing process of marble blocks and plates. This dust is carried by water to sedimentation pond. Sediment dust is removed from this pond to wasteland, but this condition have formed serious problem for environment. Because, waste marble dust is used in very little quantities even though it used in the very different industries such as construction, ceramics and cement industry, paint industry, agriculture and fertilizer industry, etc. Therefore, they have happened big mass in the waste areas (Zorluer 2003).

Marble dust, used in this study, was obtained a marble processing factory in Afyonkarahisar-Turkey. Then, it is dried and sieved with #40 sieve. The marble dust grains are smaller than 300 micron. Some physicochemical and geotechnical parameters of waste marble dust are shown in table 1, The results of chemical analysis determined by the X-Ray Flourans Elemental Analysis are shown in the table 2 (Koyuncu 1998).

Additions	WC[a] (%)	GSG[b]	UW[c] (g/cm^3)	Grain Size Distribution (%)		
				Sand	Silt	clay
Na-Bentonite	12.7	2.76	0.94	2	46	52
Kaolinite	0.1	2.64	0.59	11	26	63
Marble Dust	4.1	2.75	2.73	14	78	8

(a): Water Content, (b): Grain Specific gravity:, (c): Unit Weight.

Table 1 Some physicochemical and geotechnical properties of materials.

Additions	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_3	K_2O	Na_2O	SO_3	Mn_2O_3	LOI[a]
Na-Bentonite	59.49	18.06	4.14	3.72	2.42	0.11	0.91	2.50	0.10	-	8.55
Kaolinite	51.52	32.00	1.75	0.20	0.20	-	0.50	0.09	-	0.04	12.62
Marble Dust	0.01	0.85	0.04	55.30	0.24	-----	0.20	0.03	-----	-----	43.51

(a): Loss of Ignition.

Table 2 Chemical compound of materials.

3. Experimental Study

The changes in the strength at material against seasonal impact are determined by using freezing-thawing test. The deformation in the material as a result of this test is closely related to the amount of the water in it given that the nature and ratio of soil water changes to a grade extent when it freezes. When the water transform in to ice, its volume increases about 9% in accordance with the development of its hexagonal crystal texture (Penner & Ueda 1977).

Test specimens were prepared by 90% kaolinite and 10% bentonite mixture by dry weight for use in the impermeable clay layer. This mixture was named as control specimen - 90K+10B. Then, the waste marble dust was added to the mixture at ratio of 5%, 10% and 15%. These ratios were obtained from other studies in the literature. Marble dust is abbreviated as a MD. Specimens were prepared with compaction in a standard proctor mold by using optimum water contents for every mixture.

Freezing-thawing strength was determined according to "Methods for Freezing and Thawing Tests of Compacted Soil-Cement Mixtures" indicated in ASTM D560 (1985). In this experiment, samples are stored in a freezer at -20^0 C for 24 hours. Then, the same samples are stored at the room temperatures at 18^0 C for 24 hours. This process is called as one cycle. 12 cycles are carried out for the samples in this experiment after which the surfaces of the samples are brushed gently with wire brush to remove particles. Then, they are weighted to determine the percentage of the loss compared to their previous weight. The highest loss rate accepted in the literature is 15%. The surface crystallization and the sample deformation after the cycle are given in figure 1and figure 2 respectively.

Fig. 1 Crystallization on surface after the freezing

Fig. 2 Deformation after the cycles

4. Test results

After freezing and thawing test consisting of totally 12 cycles, it was seen that grain loss has decreased with marble dust increase. It has decreased from 17.6% to 12.5% at the end of 12 cycles. It can be declared that this decreasing can make positive influence to the strength values of layers. The less the grain losses is, the higher the soil strength is. The findings show that the strength of the samples increases when the amount of the added marble dust increases. As it is seen in table 3, an additional 5% of marble dust is ineffective on freezing-thawing. While an additional 15% marble dust results in 12,5% grain loss, an additional 10 % marble dust bring in 13,5 grain loss.

Materials	Initial water contents (%)	Number of cycle	Grain loss (%)
Control (90K10B)	25	12	17.6
90K10B +5% MD	25	12	18
90K10B +10% MD	25	12	13.5
90K10B +15% MD	25	12	12.5

Table 3 Freeze-Thaw experiment results of waste marble dust mixtures.

5. Conclusions

Firstly, it is observed that the amount of grain loss in the samples with 10% and 15% of marble dust addition as a result of deformation in the freezing-thawing test are in compliance with the highest grain loss referred in the literature.

Secondly, it is seen that on addition of 5 % of marble dust is ineffective since the results from this sample are close to those of the control sample.

Thirdly, As it is seen in figure 3, the study shows that the lowest deformation occurs in the material with 15% of marble addition.

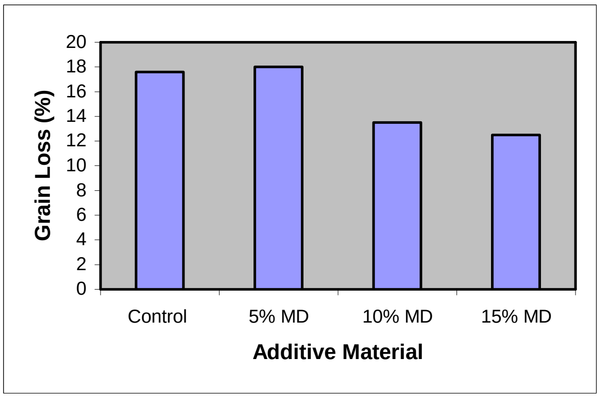

Fig.3 Effect of waste marble dust on freezing-thawing

In the light of the given findings, it can be argued that use of marble dust increases the strength of landfill liner. Trough its use in landfill liners, the recycling of marble dust will be possible. Consequently, this will not only to contribute to the protection of the environment but also to provide an economical additive material to landfill layer.

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