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To cite this article: I V Dunichkin and C Bleil De Souza 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **459** 062084

An Integrated Solution to Urban and Sea Waste Management Systems: Using Axiomatic Design to Discuss Urban Development Risks

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Abstract. The problems of preserving the natural environment of the Arctic Ocean and cleaning the Great Pacific Garbage Patch can be used to enrich business activities in the Primorsky Territory of the Russian Federation and the Eastern Sector of the Arctic. In this regard, the infrastructure of the ports of the Northern Sea Route could be seen as a new vector of development, not only taking into account the requirements for eliminating accidents and emergencies from shipwreck and oil spills, but also providing adequate infra-structure for waste treatment. This would connect the underused existing waste management infrastructure with the cleaning of parts of the Great Pacific Garbage Patch. The unstable composition of garbage from the Pacific Ocean and the waters of the Northern Sea Route require a consistent multi-level system of water and waste treatment centers using not only ships and ports, but also offshore structure. The article discusses a framework for design solutions for the urban development of the Vladivostok Commercial Sea Port and approaches to maximize the use of waste management facilities in Russky Island, using Axiomatic Design.

1. Introduction and Background

Waste management is a multi-agent and multi-objective problem with global impact. At a micro-level, it relates to waste separation by individuals; a product of information, education and adequate provision of primary waste sorting infrastructure (separated waste bins, selective waste collection, and associated penalties for not abiding to these). At a macro-level, it can be seen as contained within boundaries of each municipality therefore comprising a system of compostable, recyclables and waste to landfill with their associated transport and transfer station infrastructures. Or it can be seen as part of the larger system of global waste trade, in which normally developed countries export their waste to be treated, disposed and recycled in developing countries, meaning waste flow from the Global North to the Global South.

Final waste destination is a problem for all countries as evidence suggests a lot of it actually ends up in the oceans [1-4 to cite a few] damaging and altering costal and marine habitats worldwide. Despite floating plastic being found even in the Arctic Ocean [1], their spatial distribution is heterogeneous and mainly "attributed to the influence of oceanic currents and the emission of pollutants" [3], with large amount of debris being sucked into gigantic ocean garbage patches, such as the Western Pacific Gyre, situated in front of the East cost of Japan, at the end of the Northern sea route, which extends from Vladivostok to Yokohama.

Regardless of the scale one decides to look at, the literature normally presents decision making processes in waste management systems as related to waste generation, collection, transportation, processing and disposal [5]. Work in this area is vast in methods and case studies illustrating the location of waste management sites (landfills, transit stations, recycling/sorting centers) in relation to waste collection and transport [5-8 to cite a few]. Methods include mainly Geographic Information Systems (GIS) in combination with multi-criteria decision analysis (including Analytical Hierarchy Processes – AHP), center of gravity and clustering, and Vehicle Routing Problem models (VRP) to test financial viability and reduction on carbon emissions from transportation.

Beyond processes, there is an emphasis in what is optimum for waste management businesses, with studies showing the importance and inclusion of informal sectors [9, 10], the importance of waste sorting on the business of recycling [9,11], the risks associated to the health of workers [11], to cite a few. Some studies however, try to illustrate the penalties associated to lack of care in the location and inadequate treatment of refuse [9, 12] with the latter focusing on setting a series of environmental constraints to the placement of solid waste facilities. To the best of the authors' knowledge there is little or no work which actually examines the problem from the perspective of the city, i.e. considering the city as the 'client' for a waste management system.

This paper proposes a shift in paradigm in relation to locating waste management facilities within the urban environment: the city becomes a 'client' for the installation of waste management infrastructure. Axiomatic Design, a product design method is proposed to frame a discussion about what other requirements rather than the ones related to the waste management business should be considered when placing waste management infrastructure in the urban environment. The discussion is developed for the case study of Vladivostok, a major hub in the far east of the Northern Sea Route with interesting problems and potential opportunities related to waste management.

2. The City of Vladivostok: Problems and Opportunities

In recent years, massive investments have been undertaken in the city of Vladivostok towards transforming it into the main hub in the Russian Far East. In 2015 Vladivostok became a *porto franco*, opened to foreign and international capital [13]. Intensive development and industrialization in the area together with an increase in the city population in the past six years has led to a series of investments in new waste management infrastructures to attend the urban and industrial environments in the Primorsky Krai. As part of the attempt to bring European contemporary recycling strategies to Russia, an industrial park for waste recycling started being developed in the Primorsky Territory [14]. Besides that, a waste inventory system was put in place by the government to assist recycling in Russia with interesting proposals from [14 and 15] to create cost effective recycling technologies for ash, slag and ore tailings, important not only to industrial recycling but also domestic waste management as the byproduct of modern waste incinerator facilities.

The aforementioned initiatives show there is a will to invest in recycling and that part of the infrastructure is already in place for it to happen. However, in Russia, "waste recycling is not yet a part of the industry (…) waste with valuable properties still being mainly landfilled" [14] and there is no systemic view on minimizing waste production and consumption and a lack of economic incentives for environmental measures to be put in place such as protection systems in landfills [15]. On the Primorsky Krai territory there are 342 facilities related to waste management, among which 180 are unauthorized landfills [16]. This is because, despite installed infrastructure, very little attention is paid to recycling of domestic waste and plastic. For instance, the recycling complex for processing urban waste 'Special Plant n.1' is still underused. The plant has the capacity to recycle 400 Tons per day and 300 000 Tons per year but never reaches that volume [17]. It recycles from 10% to 13% of the total volume of waste arriving, with the remaining going to landfills which are overloaded and not properly lined causing serious risks to the environment.

A poor recycling culture together with improper landfill infrastructure is a setting for environmental disaster, bringing consequences to soil and water contamination in Peter the Great Bay [18], an area with intrinsic environmental qualities and values. This goes against the strategy to promote tourism and attract visitors to the surrounding coastal areas and beaches [19], putting pressure on the Russian waste industry to upgrade the existing landfill infrastructure, develop smart landfills, provide environmentally friendly incinerators and improve the recycling infra-structure in general starting with waste separation.

3. The Hypothesis for an Integrated Solution

Is there a way this underused recycling infrastructure can be operating at full capacity and at the same time be used to promote the city image towards it being the sustainable and an environmentally friendly hub of the Russian Far East?

The hypothesis of this study is that increasing the volume of waste to be recycled in the places such as ‘Special Plant n.1’ would be consonant with governmental initiatives of investing in waste management infrastructure and promote the viability of waste recycling industry in the area. A potential way this can be achieved is through linking with major initiatives such as the Ocean Cleanup project [20] which, via capturing devices installed either in the gyre in front of the coast of Japan or directly in coastal areas alongside East Asia, could provide enough recyclables to be separated and traded in Vladivostok. If this sort of initiative proves to be successful, the city can become a ‘client’ for the installation of a worldwide network of waste management infrastructure, which requires careful planning and a clear framework for growth and management.

Principles of Axiomatic Design (AD) are proposed to develop design specifications and manage constraints related to the location of new infrastructure facilities to cope with this increased demand. AD provides a design specification model based on four different domains: the Customer domain in which customers’ needs and aspirations are specified; the functional domain in which functional design requirements are specified; the Physical domain in which design parameters to meet requirements are specified and the Process domain which is concerned with the manufacturing of the parameters specified in the Physical domain [21].

Upper level functional requirements for a sustainable and profitable waste management business [5-12] are mapped in Table 1 together with upper level functional requirements for a sustainable city [9, 12 and 22]. These requirements are discussed in relation to the zoning system as established by the Master plan and land use and development rules for the city district of Vladivostok [23].

Table 1. Upper level functional requirements.

Waste management Businesses	**Sustainable City**
Meet capacity:	No pollution in the air, soil or water:
- Transport vehicles	- From transportation
- Transit stations	- From landfill
- Recycling centers, landfills, incinerators	- From incinerator
Efficient transportation:	Preferential areas for location of facilities:
- Accessibility	- Industrial areas
- Service time and frequency	- Environmentally damaged areas (e.g. Quarries)
- Distance from collection to transit station	- Disused industrial areas
- Distance from transit station to recycling center, landfill or incinerator	- Away from urban area
- Minimize interference with existing traffic and local roads	- Away from sensitive buildings (e.g. hospitals, schools, religious sites, etc.)
	- Away from woods and orchards
Land allocation:	Hygienic facilities:
- Low cost of land	- Proper enclosure
- High proximity of collection points	- Proper lining and drainage

Besides requirements, the following constraints from a city perspective in relation to areas suitable to accept landfills: (i) sites with elevation above 1200m; (ii) areas prone to landslides; (iii) areas prone to flooding; (iv) areas which are closer than 300m to the seafront; (v) sites with shallow water table; (vi) sites closer than 200m from water sources; (vii) national, regional and urban parks; (viii) areas of conservation of natural habitats, fauna and flora, (ix) archeological sites and (x) 100m away from geological fractures or faults.

Absorbing refuse from the such as the Ocean cleanup project, implies providing additional facilities for seagoing ships for waste collection, offshore platforms for temporary storage and primary sorting, port sorting zones and waste recycling centers in Primorsky Krai. Potential areas to locate waste management infrastructure are in the Western parts of the port area, where, together with new terminals for receiving containers, it is possible to place a separate pier for the acceptance of refuse collected by ships and partially sorted waste. Transport to 'Special Plant n.1' located on the Russky Island can be made by ship or road via the new suspension bridge. However, traffic from the harbor reaches the island through the Pervomaisky District, where there are a significant number of residential areas, affecting the quality of the city transport network, which is located in a difficult relief, containing multiple interceptions and low transport carrying capacity.

Vladivostok is a heavily motorized city with the predominant use of individual vehicles [24], meaning any overload on traffic would not only congest the city network infrastructure but also increase air pollution. A concerted action with local public transport can potentially provide a temporary solution to the problem and/or a permanent one in peak times of waste transportation if a management structure between passenger and waste transport are put in place and a more reliable public transport system is offered as an alternative to private vehicles. A careful study of the traffic conditions in this part of the city would be necessary to plan this capacity increase with appropriate percentages of waste transport to be allocated by road and the rest complemented by ships.

A general analysis identifies environmental risks for residential areas (air pollution and increase in air dust), for any scenario of operation of the waste disposal center on the Russky Island. This location is optimal relative to the summer south-eastern and winter northern wind directions. However, the city topography largely affects the wind patterns and as a result the quality conditions of the air [25-26], making it difficult to disperse pollutants from road traffic, meaning any increase in traffic flow could be seen as problematic. Apart from that, replacing landfills by incinerators and re-using ash and slag from them to generate energy would also increase the amount of particles in the air, negatively affecting the population quality of life.

Promoting the use of public transport, diverting large parts of the waste transport via ship cargoes and proposing a careful combination of final waste destination sites (mix of landfills and incinerators) located in industrial areas less affected by the unfavorable wind condition could mitigate predicted pollution from expanding the waste management business in the city especially if these are done in combination with the provision of green areas as shown in [25]. From this point, functional requirements and design parameters to meet these requirements need to be examined at a lower level so compatibility between what is required and what can be achieved can be realistically assessed.

4. Conclusions and Suggestions for Future Work

This study proposes the city is considered a 'client' when waste management facilities are to be located within the urban environment. It sets the basis for Axiomatic Design to be used in framing the discussion about what requirements beyond those from waste management businesses need to be considered when placing waste management infrastructure in cities. The case study of Vladivostok is explored to show how underused waste management facilities allied with a shift in policies, to upgrade waste management infrastructure towards EU standards, can be used to promote the image of the city as sustainable and at the same time attract new economic investments: by accepting refuse from initiative such as the Ocean Cleanup project to be separated and traded in the Russky Island. Upper level functional requirements for a sustainable and profitable waste management business together

IOP Conf. Series: Earth and Environmental Science **459** (2020) 062084 doi:10.1088/1755-1315/459/6/062084

with functional requirements for creating a sustainable city are listed and discussed mainly in relation to their impact in city transport and air quality.

Whereas traditional methods from waste management literature would probably see these requirements as conflicting with each other, potentially addressing conflict resolution via attributing a weighting system easily to be criticized (e.g. Multi-criteria analysis, Analytical Hierarchy Processes, etc.), AD provides a framework for them to be addressed together. A framework based in AD relates design success with its inherent complexity in terms of information content, disproving the need for a weighting system by stating the “probability of success can be computed by specifying the design range for the functional requirements and by determining the system range that the proposed design can provide to satisfy them” [21]. It acknowledges that there is no best solution but a set of thresholds below which requirements cannot be satisfied neither for the city nor the success of waste management businesses. This shifts the assessment process from optimisation to comparing tolerances and opens the design problem to accept multiple satisfactory solutions facilitating negotiation among different stakeholders.

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