Construction Waste Management:

Case Studies YIT Russia

Overview of construction waste management at YIT construction sites and suggestions for further development

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Abstract

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Abstract

The purpose of this bachelor thesis is to understand how construction waste is handled and what can be improved in the cases of Russian construction sites. Additionally, this paper proposes new ideas for construction waste development and ways of tracking the progress.

Before the qualitative case study, background information on the construction waste was researched, development directions for on-site waste management and design stage strategies were overviewed. The case study included three construction site observations, waste reports analysis and other sources of information. Various technological processes were observed as waste origin points. The findings are documented and taken in account with the attempt to combine different criteria from on-site waste management and waste management at the design level. The studied construction sites proved to be well-organized and with the use of BIM, the company has already started practicing waste avoidance. Although no waste sorting is done at the sites, apart from metal materials separation, there is a good ground for further advancements.

The results include an evaluation of the studied construction projects through positive and negative criteria observed. Based on the findings and the gathered theoretical background, development directions were proposed. In addition, author’s own ideas on development and progress tracking were suggested. All suggestions require further research for proper implementation, creating room for discussion.

Keywords

CDWM, CDW, construction waste, waste management

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1 Introduction

1.1 Aims of study

This bachelor thesis was carried out to review the current situation with construction waste in Russia, as well as assist the development of construction waste management in the Russian department of the YIT Corporation. On the basis of the EU Directive mandating 70% of waste by weight to undergo material recovery such as recycling, reuse or other in the European Union (Directive 2008/98/EC), YIT planned to bring responsible waste handling to Russia. Promoting construction waste management improvement agenda in the Russian Federation in general and bringing attention to the issue is a vital part of the progress. Waste management includes various stakeholders, including waste production parties, waste collection and utilization companies, and the government, which in its terms can provide the most incentive for change, especially against many negative factors, influencing the current image and practices of waste management.

Construction and demolition waste (CDW) is often considered as a single type of waste. However, this thesis focuses solely on the construction waste (CW) and construction waste management (CWM). CWM is an integral part of maintaining a clean environment and creating a circular economy.

The main objectives for the study are as follows:

- To analyze CWM cases on YIT construction sites;
- To understand what areas of CWM could benefit from optimization and how;
- To understand the current situation of CW in the Russian Federation.

The main research questions for the study are as follows:

- How is CW handled on the construction sites?
- What areas of CWM need to be improved and how?
- What is the situation of CW in the Russian Federation and what practices can be adopted ?

1.2 Construction waste situation in EU and Russian Federation

According to the Study on Resource Efficient Use of Mixed Wastes (Deloitte 2017, 7) for the European Commission, CDW creates over 800 million tons per year and its stream of waste is one of the heaviest and most voluminous. CDW accounts for roughly 25-30% of all waste produced in the EU.

Main constituents of CDW are:

- Concrete
- Bricks
- Gypsum
- Wood
- Glass
- Metals
- Plastic
- Solvents
- Asbestos
- Excavated soil.

Most of CDW material is highly recyclable and reusable, some components of CDW have high resource value, and there is an established market for re-use materials collected from demolition of roads, drainages and other, i.e. bitumen and aggregate from asphalt roads, bitumen roofing tiles.

Recycling of CDW in the EU is yet to reach its full potential, with the performances of recovery of material varying for the Member States of EU greatly, from 10% to more than 95%. Member States with highest performances provide proven practices for the low performers to achieve better results (Deloitte 2017, 7). It is also important to state, that official CDW data is often not a completely reliable source of information (Deloitte 2017, 40), however it can still provide context for comparisons.

The Russian Federation experiences a rapid increase of new construction. According to the Federal State Statistics Service construction has grew by a factor of 3.4 by cost volume in the span of 5 years from the year 2000 to 2005, and has amounted to 1711.7 billion rubles. While there is also a clear annual increase in built apartments. (Oleynik 2016, 2.) Officially CW drew a total volume of 62.57 million tons in 2019 in the Russian Federation, which places it at 0.83% of all industrial waste generated in the country, including mining (Finexpertiza 2020). While in such percentage context it may seem unsubstantial, 62.57 million tons is a massive volume of waste, putting Russia ahead of most of the European countries by construction waste generation. The growth of the construction industry is also accompanied by many issues in waste management.

Environment contamination and potential profit loss are not the only problems that we face. It is considered, that construction and demolition waste only occasionally contains any harmful materials, thus it falls into categories 4-5 by the Order of the Ministry of Natural Resources of Russia N 536 (2014), the categorization being established in terms of hazardousness in the Federal Law №89 (1998, section 4.1). CW is considered fit for landfilling, often without any liner material, making it cheap to deal with construction waste and harder to control illegal waste dumping, marking that as a primary example of miscellaneous issues, brought about by undeveloped waste handling practices.

1.3 Aims and regulations in EU and in Russian Federation

The European Parliament and the European Council provide the EU with wide guidelines and frameworks on regulating waste management in the Member States of the EU. These guidelines with the help of thorough studies of the waste situation in the EU, such as the Development and implementation of initiatives fostering investment and innovation in construction and demolition waste recycling infrastructure (IDEA Consult 2018) study, and the Resource Efficient Use of Mixed Waste (Deloitte 2017) are aimed at aiding the development of Member State waste management situation. Frameworks and guidelines are provided via the Circular Economy Package, consisting of the regulation for the organic production and, more to the issue of CW, four directive amends published in the Official Journal of the European Union (EU Directive 2018/851) and other documents, like the Construction and Demolition Waste Management Protocol (Ecorys 2016) and the EU Guidelines for audits before demolition of buildings (2018).

The Circular Economy Package legislation amends in form of directives:

- Directive (EU) 2018/849 of the European Parliament and of the Council of 30 May 2018 amending Directives 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment. (EU Directive 2018/849.)
- Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste. (EU Directive 2018/850.)
- Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste. (EU Directive 2018/851.)
- Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste. (EU Directive 2018/852.)

In general, the EU directives are aimed at conserving and improving the quality of the environment and promoting rational use of resources. The key goal of the Package is to further adopt the “waste hierarchy” (Directive 2008/98/EC), that puts in a priority order types of waste management practices, going from waste prevention as a top priority measure to waste disposal as the last possible solution.

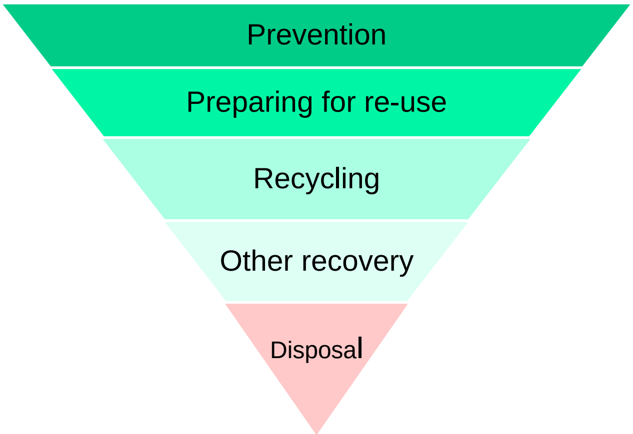

Figure 1.1 Waste hierarchy (Directive 2008/98/EC)

In the Figure 1.1, you can see how the waste management practices go from most desirable and optimal for a sustainable environment and economy to least desirable, meaning stakeholders must go from each upper step to the lower only in case if the higher priority measure is impossible to carry out. The *Waste Framework Directive* offers a framework for improving resource efficiency in the European recycling society, mandating Member States to reach a minimum of 70% by weight of non-hazardous CDW to be re-used, recycled or be otherwise recovered. While most of the European Member States are already exceeding the 70% mark by 2016 (European Environment Agency 2020), they set the standard for other countries, which are still working towards reaching the set goal.

The Framework provided by the directives implies more precise measures to be taken by the Member States and encourages creating local policies for advancing towards sustainable society. Thus, the Member States provide their own plans and set their own targets, according to the wider guidelines. An example of further development is the National Waste Plan of Finland, From Recycling to a Circular Economy (Laaksonen et al. 2018). This paper sets the course of action for handling all waste and construction waste in particular. It emphasizes the specific goals and approaches, and assigns the responsible parties.

The discussion about waste handling in the Russian Federation has been slow paced at the government level, leaving municipalities unguided. Moscow has already started moving towards the right direction by implementing laws for construction waste transportation tracking, mandating contractors on supplying tracker devices and waste weight monitoring equipment on construction sites and waste polygons. Additional emphasis has been made on setting the priority for recycling of waste over landfilling. (Moscow City Construction Department 2019.) Be that as it may, municipal regulations are not enough to make a significant advance towards better waste management on the national scale. Existing waste handling strategies and priorities are yet to be adopted in a form of regulations in the Russian Federation, leaving the country’s waste management in an unsupported state. Such regulations as setting a firm priority of waste utilization before landfilling and waste ownership regulations could greatly help raise control over the waste management situation and assist those responsible parties in their attempts at implementing circular production practices.

Russian administration seem to be aware of the state of the waste management situation. As stated by Glovatsky et al. (2008), representing the Russian Federation, Deputy Head of State Environmental Control Department of Rostechnadzor of Russia, V. A. Sapozhnikova said, that the administrative regulation is not the only issue, with other problems emerging from financial and economical regulation, and that there is a strong need for a federal program for waste management. Nevertheless, during the last decade no significant move has been made, with similar demands from the environmental enthusiasts now as then. Thus, the request for setting responsible government bodies for the control of waste handling is still prevalent, while federal, regional, and municipal responsibilities and credentials are separated in an unsatisfactory way. It was mentioned in the same publication (Glovatsky et al. 2008), that existing sanctioning by the supervisory authorities is not on par with the level of danger to society and the wide spread of waste handling offences. Yurchenko in his publication (2019) also states dissatisfaction with the waste regulatory system of the Russian Federation, stating that financial penalties for negative impact on the environment in current regulations are foremost aimed at budget replenishment and not the preservation of the environment.

The positive drive for the change towards the circular economy around the world has the power to influence states, pursuing sustainability. The ongoing discussion and advancements in one state alone have the power to show their value and prove profitability in the economic and environmental spheres. Furthermore, today with most commercial organizations being international, it is inevitable for proven sustainable practices to make their way around the globe, further unifying states' visions towards sustainability, driving us towards a better future.

1.4 YIT Corporation

The commissioner for this thesis, as already mentioned previously, is the Russian department of the YIT Corporation. The YIT Corporation is the most significant construction company in Finland and one of the most influential construction companies in the Northern Europe. YIT operates in 10 European countries, including Finland, Russia, Sweden, Norway, Estonia, Latvia, the Czech Republic, Slovakia and Poland. The company is focusing on creating sustainable urban development and specialized projects. It is engaged in constructing housing and residential areas, developing business premises, building infrastructure, property investments and renovation services. In the Russian Federation YIT provides such services as housing construction, property management services, road and infrastructure construction, industrial park development and other. According to the 2016 rating of the largest construction companies in Russia by INFOLine (RBK 2017) YIT has placed 8th place and later got the title of the most influential Finnish company in Russia of 2018, according to Fontanka.ru (YIT 2018).

YIT sets long-term goals for reaching sustainability and circular economy in all of their areas of operations, including the Russian Federation. The basis of the company's strategy for 2020-2022 are urbanization, digitalization and sustainable development. To realize the strategy, YIT has implemented four development programs: Performance, Customer Focus, Green Growth, Services Development, and makes efforts towards reducing its impact on the environment. (YIT 2021.)

2 Overview of construction waste management

2.1 Construction waste management impact on environment and economy

Construction waste management has its influence on the environment in all stages of the construction process. Waste is generated during acquiring raw materials, during the production of construction materials, at the construction site and during the exploitation stage, up to the deconstruction or demolition of the building or structure. As well as residue mineral materials, that accumulate through most of the stages of construction, other waste is also being generated during the technological processes of manufacturing and the exploitation\service stages. More than 90% of open-pit mines in the Russian Federation are purposed for the subsequent production of construction materials. Mineral raw material is often acquired through the open-pit method, which causes number of negative effects on the environment and the economy. Such effects are destruction of soil, disturbance of water regimes, air, water and soil pollution, birds and animals leave their habitats, vast areas of land are being rendered unusable for farmer activities. (Oleynik 2016, 2.) These repercussions translate into significant loss of habitable and useful land, cause great disturbances for the local flora and fauna, relocate range animals and ruin the natural balance in the area. Another influence, that CWM has on the environment, comes from the practices used to manage hazardous or toxic materials, where improper handling may result in damaging soils or waters, creating health risks for the population and future negative effects on nature, with possible excessive depletion of natural resources.

Economically, apart from unnecessary loss of valuable natural resources, poor handling of construction waste creates a number of unfavorable circumstances. Excessive amounts of waste being dumped in landfills results in a premature filling of landfills, driving further expenses on new landfill preparations and on fixing the negative effects on the environment. Lost opportunities of industrial symbiosis, where strategies like input replacement (Fraccascia 2016, 87) could significantly lower finances spent towards input materials by lowering the share of virgin materials with the inclusion of wastes in their place. Embedded energy, hidden in the waste materials, being wasted by not saving it via replacing virgin materials with recycled materials (Roussat et al. 2009, 12-20). Proper construction waste management is essential for maximizing material use and increasing resource efficiency, while minimizing costs and producing sustainability. This is achieved by relying more on recycled and re-used materials, lowering the demand for virgin materials.

Waste management development has potential to free the environment from undesired pollutants, while providing financial benefits to the stakeholders, material manufacturers, waste contractors and construction companies. Sustainable waste management development is often overlooked in the developing countries, with organizations prioritizing more imminent financial gains and because of a lack of a holistic approach to the issue from the hierarchy of stakeholders (Agamuthu et al. 2020, 16-17). Effective regulations and laws failing to be adopted create a more difficult background for changes in favor of better sustainability. Not investing in more responsible waste management strategies means ignoring risks of potential environment harm and missed economic benefits.

2.2 Waste management at construction site level

Construction site administration governs all activity on site, including the maintaining of cleanliness and waste handling. That way waste management on construction site level is one of the key important areas, when discussing CWM effectiveness. CWM on construction site has the power to decrease the amount of money spent on raw construction materials, increase work efficiency, supply fit for reuse or recycling material and other.

According to the International Report on Construction site management and minimization (Macozoma 2002, 25), the benefits of CWM on site are as follows:

- Avoidable waste generation reduction on site;
- Prevention of waste of entrance the national waste stream and waste redirection;
- Minimization of waste transportation costs;
- More efficient material procurement due to higher efficiency of material use and use of secondary materials;
- Optimizations for the protection of contractor’s margin;
- Site efficiency and performace growth.

These benefits are due to a number of methods of waste management on site, being implemented by stakeholders (Macozoma 2002, 25):

- Waste specifications;
- Waste management contract language;
- Strategies of waste avoidance;
- Waste management planning;
- Procurement and use of recycled and secondary materials and products;
- Site efficiency and performace growth.

Many of the above mentioned methods and the derived benefits circulate around the idea of waste avoidance, as it is far easier and more effective to avoid waste at first, than to deal with it later. With the increasing responsibility and awareness of every man involved into the construction industry, waste avoidance may become the most effective waste management practice on sites. By preventing waste from ever occurring in the first place many expenses on site cleaning, waste collection and disposal can be avoided. Macozoma (2002, 14) creates a useful guideline for waste avoidance and separates its concept into three representative components: waste prevention, waste demand management, and waste reduction.

While the design stage has a big role in preventing waste, as mentioned further, site management is also noticeably involved. Changes or mistakes are not an uncommon scenario on a construction site and often decisions are made on-the-spot, which influences further procurement and work processes. The human factor, poor communication and the lack of a clear action course serve as an origin for many waste emergence opportunities, in form of package waste, excess material and material loss due to bad storage. Excess material can be produced usually through installation procedures even by correct following of the technological process, so the choice of material is important in that case, apart from controlling the correct installation process. Extra unnecessary waste is also being imposed by poor procurement and storage organization. More specifically, material handling during delivery, uncovered storage of materials that could be damaged by water or other hazards, poor placing of material putting it at risk of mechanical damage. While also, a significant part of procurement is ordering recycled or secondary materials instead of new, where possible.

Demanding a strong response from contractors generating waste, waste collection and sorting is a viable technique of reducing waste, subjected to landfilling. By waste sorting the separation of useful material for later use or recycling becomes achievable. According to Poon et al. (2001), on-site waste sorting in one of the best measures of CDW management, and in our terms in CW management as well.
CW consists mainly of two parts: inert and non-inert material. Inert material is usually represented by concrete, bricks, rocks, soil and sand in CW, whereas non-inert materials are materials like plastics, biodegradable materials (wood, paper, etc.). Early separation of inert materials from non-inert provides significant additional value to CW. Inert waste is a viable choice for backfilling, pipe bedding, forming of embankments or other similar uses, as it rarely includes any harmful to the environment materials. Left over material could also be given back to material suppliers for strengthening business symbiosis. However, non-inert waste should be foremost considered for reuse or recycling, as it offers high value and potential for recovery, but landfilling should be viewed only as a last resort, when no way of recovery is feasible, while special emphasis should also be put on landfill space saving for other materials. This being said, such decisions are not a common occurrence in construction companies. As those companies are moving towards more responsible strategies, they face obstacles, which turn them to a halt. Such obstacles are significant initial expenses, deficiency of qualified workers and expertise, lack of legal authorization. With the most significant issue for the stakeholders being the expenses factor (Shen Tam, 2002).

On-site sorting is an optimal CW management technique for separating potentially useful material and supplementing additional value to it. Value of this material can be measured in both economical, and environmental gains. From the point of view of the economic benefits, effective waste sorting decreases disposal costs, offers the prospect of selling the material for reuse or recycling, and in the meantime sets grounds for establishing symbiosis relations with contractors. Environmental gains, on the other hand, manifest in saving landfill space and preventing potential area contamination from mishandling of materials. However, on-site waste separation comes at the price of requiring additional space and equipment on the construction site for accommodating effective sorting and preventing mixing of materials, as well as higher level of responsibility and skill from workers and the site administration. These requirements influence on the design stage of the project, demanding more rigorous site planning, schedule planning, human resource assignations. Apart from the mentioned drawbacks, on-site waste sorting is also capable of disturbing established workflows, confusing workers and bringing about delays. Although, persevering and arranging a good CWM on site is of a great value, not only because of the reasons mentioned above, but for building a good public image and gaining recognition from customers.

2.3 Waste management at design level

As put at the first step in the waste hierarchy, shown in the Figure 1.1 above, waste prevention is the most logical and least resource consuming waste management strategy. Construction projects are significant in their scale, long lasting and investment intensive. With its complicated nature, construction industry has many stakeholders, and approaching construction waste management is a difficult topic. Nevertheless, preventing excess waste from ever occurring significantly simplifies other waste managing practices directly, due to fewer waste to deal with. Reduction of waste can achieved by means of choosing the right material with high application efficiency, negating waste generation through compilation of excess material. The material packaging, worker skill required for the installation without extra material loss or other technological features of any given material have the potential to make the design noticeably more sustainable, removing unnecessary trouble. Furthermore, designs, that keep the end of the building’s lifecycle on the agenda, succeed in the waste management by far, by means of choosing such a material that can be easily deconstructed and used elsewhere. Proper material choice and choice based on versatility have also the ability to compensate for over/understocking of materials, with other projects in mind, so that materials from one project can go to another.

Designing and planning a new construction, renovation or other project in the building sector is a dynamic process involving the practice of creating multiple designs, close contact with stakeholders. It is near to impossible to plan every detail perfectly from the start, so series of trial and error continue through the design and planning stages, almost always making their way into the stage, at which the construction has already begun and lasting up until the end. This means that mistakes leading to reworks are bound to happen at some scale, resulting in increased costs and additional waste.

Errors in design are certain to appear at some point due to the overwhelmingly substantial scales of projects. Ajayi et al. (2017, 14) mentioned the most weighty causes of errors in construction, according to other authors, as follows: unsatisfactory design documentation (Oluwaseun & Olumide, 2013), lack of dimensional coordination (Crawshaw, 1976), inconsistent procurement documentation and bad fixation of responsibilities, inept communication (Osmani, 2012), documentation delays (Koskela, 2004) and lack of involvement from contractors into the design (Arain et al., 2004). Projects require teams of professionals working together and adjusting their individual designs to one another. In the modern world these errors are becoming easier to manage by digital technologies such as Building Information Modeling (BIM). Implementing BIM into the workflow allows for the creation of more holistic designs, less susceptible to mistakes by oversight, while also creating an open space for fluid communication between specialists of various fields, negating collision of models. Building models are following the construction through the entire process, ensuring rational use of materials. Another occurring issue, brought subsequently by poor design and planning management, is material over- or understocking. Poor information communication through on-site documentation with room for human judgement calls is a weak point for carrying out robust designs, resulting in excess material or damaging schedules, as aforementioned leading to unnecessary waste and extra costs.

Proper implementation of BIM has proven to lead to easier and precise information handling with unified system of documentation management. BIM is essential for proper design coordination in the modern world and is already being set as a standard in many construction companies. The use of BIM is already set as a mandatory condition for developing any construction project for a government contract in the Russian Federation. In terms of CWM, all of the above said positive sides of BIM directly contribute to minimizing CW coming from unnecessary reworks or other mistakes occurring on the construction site. However, BIM is also enabling larger view of projects, making easier to predict causes of waste. And the ever increasing market of BIM tools help contractors familiarize better with the initial designs and plans together with the documentation, allowing the prospect of informed feedback for minimization of waste.

2.4 Areas of improvement opportunities

2.4.1 Waste avoidance, collection and sorting

As mentioned before, there is plenty of growth opportunities in both areas of influence on the CWM, at the construction site and in the design phase. In this case, it is vital to take the potential waste generation into account and mitigate the human factor issue by arranging guidelines and norms, clear communication and feedback systems. Here all the principles of good waste management on the design level are also applied, such as foreseeing the end of the building lifecycle and providing easier deconstruction, understanding work processes to decrease excess waste material generation etc. Waste avoidance is practiced by proactively searching for ways to minimize waste generation in the first place. Waste avoidance in design and on site must base on the idea of sustainability and rationality.

Waste avoidance can be implemented via:

- Mindful choice of materials for easier and cleaner deconstruction;
- Procurement of precise amounts of materials;
- Specifying reusable and recyclable materials;
- Clear management communication;
- Creating storages for reusable or extra materials for later use;
- Inter-project sharing of materials;
- Opting for reusable packaging and containers;
- Staff education on material efficiency and implementing responsible organizational culture.

The basis of construction waste management on site or the movement towards efficient waste collection and sorting lies in efficient construction management itself. Setting clear responsibilities for each contractor, clear management and demands, with fair rules for everybody, makes the foundation for implementing any kind of new practice.

Solid guidelines are to be adopted for ease of sorting to make the process fluid and less of a puzzling experience for the workers. Every new innovation is usually met with negation at first, as workers have already developed a certain working culture. That is why staff education is as important as the technological side of adopting waste collection and sorting.

Construction site waste can be separated into inert and non-inert materials as already mentioned before. Inert waste, consisting of glass, metal, concrete, bricks and blocks, rocks, mineral insulation materials, soil and sand is a viable choice for backfilling. Such materials as concrete, bricks, blocks, and rocks can also be used as a substitute for course concrete aggregate, as the world sees a surge in research concerning secondary materials in the role of aggregates in concrete. Soil and sand, when separated can be used for creating green areas around the street infrastructure if a project involves such development. Non-inert materials like plastics, wood, paper, and biodegradable materials are foremost to be considered for reuse, recycling or recovery.

The first and main key to proper waste sorting is separating the inert and non-inert waste from each other. Inert waste can become useful as already described, and usually fees for landfill of inert waste are lower than for non-inert or mixed waste. Further separation depends on the particular situation and potential directions for the materials. A company should know in the planning stage, which organizations could be utilizing the waste streams, then the materials should be separated from the inert waste, and so on. Effectively every individual sorting bin for any individual sort of material should have a direct purpose. It is also important to note that some waste handling contractors around the world provide their own sorting facilities, rendering on-site sorting optional, in this case the waste collector is responsible for the further actions.

2.4.2 Circular business and business symbiosis opportunities

The movement towards circular economy is gaining momentum in the late years, and the main idea of the new view on economy is to increase the value of products and materials they consist of. In contrast to the dominating linear economic model, that is characterized by going from a raw material to production, then to usage of the product and to disposal as a non-recyclable waste. Circular economy takes the value from disposed materials and side streams into the production and creates a closed cycle, where disposed products or their materials are recovered for further use. According to Diemer et al. (2017, 235), there is three main opportunities for resource interchange between industries or companies: by-product reuse, utility and infrastructure sharing, and joint provision of services. This is very much applicable to the construction industry, as a material the CDW is for the most part non-hazardous, relatively easy to sort and has a strong value when separated. Thus, circular business opportunities in the construction sector are opportunities to set circular practices of material circulation and provide additional place for business-to-business collaboration, establishing business symbiosis.

An essential part of a circular business in construction is reducing produced waste and maintaining the material within the production cycle, whether to use material as a fill-in at a construction site or to use as a material for producing construction materials in a factory. Such materials acquire additional value due to long lifecycles. The main area for business collaboration and responsible material use lies in effective resource exchange, which can be carried out via internal and external exchange (Fraccascia 2016, 86-87). This means that waste or separated materials can be used again within the same company or given to other.

Internal exchange in terms of CW means use of extra material or sorted material on the same construction site for different purpose or in other projects within the company. This can be done by separating out predetermined useful materials and storing them or sharing them between projects. An example of such practice could be a situation in which the Project №1 has supplied an extra amount of rebars that exceeded the necessary amount, and the Project №2, being aware of that, requests the rebar from the Project №1 and combines that supply with the new procured materials, instead of procuring the entire needed amount from the supplier.

External exchange brings true business symbiosis to life by setting a material exchange pattern between organizations. The waste generated on a construction site has potential value in the form of useful materials in it, that could be appropriate for use at a production in other companies. The external exchange can be adopted via three business models: input replacement, co-product generation and new product generation with use of materials derived from waste. Input replacement is a method of substituting input virgin materials for producing products in an organization, thus lessening the amount of virgin inputs required for producing one unit of output. The value is gained by improving production technology to accept materials derived from waste as an input, but also value is preserved and enhanced by saving on virgin material purchases, waste disposal fees and improving the image of the companies. Co-product generation is another method similar in the sense of adopting materials derived from waste into the production process. The idea of co-product generation lies in creating a new product viable for selling, that has a more environmentally sustainable production process or with better features than the original product made with virgin materials.The last business model proposed by Fraccascia (2016, 85-87) is new product generation. The gist of this model is in creating a completely new product for sale while creating a new business that is built entirely on industrial symbiosis.

2.4.3 Use of digital technology

As with all spheres of industrial production, digital technology has already made its way into the construction industry. The biggest advancement in the building sector in the latest years has been the introduction of BIM. Although there is no direct influence from BIM on waste, it has its intermediate effects. BIM allows for a more rigorous and systematic designing, that in its turn creates the possibility for consideration of more input information for the designs. Such input information is the minimization of produced waste in a new building project for example. As stated by Mahlet & Yudhi (2017, 67) in regards to BIM, waste prevention may be the best solution in CWM. By simplifying and improving design mistake detection like collisions or element mismatches, BIM holds the power to significantly reduce reworks on the site. BIM models are also volumetric information models of building, which drastically improves design perception by customers and helps set on a design better. Reworks are a significant origin of unnecessary waste and a direct result of poor design and changes in designs during the process of construction, which is confirmed by Won et al. (2016).

Another use that digital technology is finding its way into construction is through the Internet of Things (IOT). IOT describes a concept of gadget-to-gadget interaction, where data is transferred over a network without the human intervention. This allows for creating automatic systems for virtually any kind of monitoring or management. The IOT technology can be beneficial for use on construction sites in a variety of ways, that way also for construction waste management. For example, waste tracking via IOT devices is already being used in some places, for example, Moscow has introduced laws mandating waste handlers to use such devices to monitor where the waste is being disposed (Moscow City Construction Department 2019).

3 Case studies at YIT Saint-Petersburg sites

3.1 Research methodology and analyzed projects

The raised research questions are applicable to any construction site. In this research topics were investigated at the three construction sites in and around the city of Saint-Petersburg, following the case study methodology.

Choosing the right approach for the research is a vital part of any study, and depending on the essential questions raised in the investigation, it should be chosen carefully. Selecting from qualitative and quantitative research, qualitative has been adopted as the main approach in this case, being more suitable for the issues at hand. As implied by Flyvbjerg (2006), qualitative, single case study is a powerful tool for acquiring new deep knowledge about phenomena. By approaching the studied objects from within and understanding their complex structures it is possible to get a finer insight into the small structures and causes of some phenomena.

In order to conduct this research, the qualitative approach was chosen as an efficient method of obtaining good understanding of phenomena, with possibility of in-depth learning about certain causes and behaviors. As this study foremost is learning the used practices and ideas, qualitative approach should provide a better starting point for the further developments. The idea of approaching the problematics with a qualitative approach is due to the need to achieve detailed understanding of various sides and perspectives on the construction site. This is important for later development, as with the large amount of stakeholders it is crucial to get ideas directly from the ongoing construction phases and day-to-day interactions. Because the research questions try to open the topic from multiple approaches, the real-life context in the form of case study suits well to help to create development suggestions for the future.

The case study's field research was carried out at three YIT construction sites, viewed as projects under one organization in the form of YIT to consider inter-project communication. The case studies were selected as the methodology to carry out the research. In this case the content had a qualitative approach, as stated above. Case studies consisted of visits to each construction site, a tour around the points of interest on site, accompanied with a thematic interview about internal operations and behavioral overlooks, as well as inspection of relevant documentation, and a quantitative overview of waste output situation around cities (Figure 3.1). The documentation of the study was supported by photos from the sites.

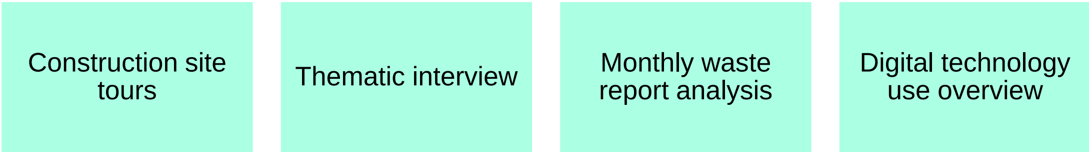

Figure 3.1 Information sources for the study.

For the field research three construction sites were selected, two of which are located in the city of Saint-Petersburg and one in the town of Pushkin.

- "Inkeri" in the town of Pushkin;
- "Novoorlovsky" in Saint-Petersburg;
- "Tarmo" in Saint-Petersburg.

On each construction site a walk and check tour was carried out between various points of interest. Every different kind of construction process, which was available at these sites from groundworks to final decorating works has been viewed with special attention towards generation of waste, material choice, technology used, and work culture. By direct observation, practices of on-site waste management were examined, on-site cleanliness and waste collection activities were given special attention, as well as waste collection points.

For a larger view of the waste situation YIT waste reports were analyzed (Appendix 2, Appendix 3.) and a short interview about site responsibilities, resource sharing, contractor behaviors (Appendix 1.) was taken with the head of technological supervision. Use of digital technology at the design level was evaluated based on materials describing BIM usage at YIT in the articles by Krylov (2019a; 2019b, 138-143) and Maltsev (2019, 143-148).

Before construction site visits a mandatory safety training was carried out. The Russian department of the YIT company obliges to the rules and guidelines effective in the Russian Federation and provides its own safety training. The safety training consists of the construction site entrance regulations, introductory seminar and safety educational films, introduction to personal safety equipment and information about fines for safety rules violations. The seminar covers all main aspects of safe on-site behavior and potential dangers and puts special emphasis on being aware and predicting potentially dangerous situations in advance.

As well as the conventional safety training, special behavioral and hygienic instructions were given, as the study was conducted at the time of COVID-19 pandemic. Access to the construction site was made possible only after a quick temperature check and overall health evaluation, special distancing rules were implemented on site and in the administrative facilities, antiseptics and respiratory masks were also provided.

After the safety training proper safety gear was provided, which included special construction footwear, safety glasses, construction helmet and a respiratory mask.

3.2 Project site descriptions

YIT is realizing a number of complex residential areas in a number of cities in the Russian Federation and in Saint-Petersburg in particular. The projects include construction of residential housing in the form of blocks of flats, internal infrastructure, and in some projects also municipal buildings like schools and kindergartens. The construction sites are situated in the city of Saint-Petersburg and Pushkin, Leningrad oblast.

The first project, “Inkeri” is constructed on the Gummolosary street with the buildings belonging to the Kameronovskaya, Push’inskaya and Lomonosova streets, in the southern part of Pushkin, Leningrad oblast. The complex will consist of four sectors and a total of 29 low-rise buildings for the current stage with further territory development. With 3 of the 4 sectors being already commissioned, the construction works are being performed at the 4th sector, which is where the visit has been carried out. The surrounding streets and yard areas are also under the development by YIT. The residential buildings share a common material choice as well as work technology. Structural material choice for the residential buildings are as follows: cast-on-situ concrete foundations, cast-on-situ concrete walls, concrete blocks for intermediate walls, cast-on-situ concrete floor slabs, rolled bitumen roof cover and galvanized steel sheeting, mineral wool plates for external thermal insulation. The energy efficiency class of the buildings is “A”, meaning very high.

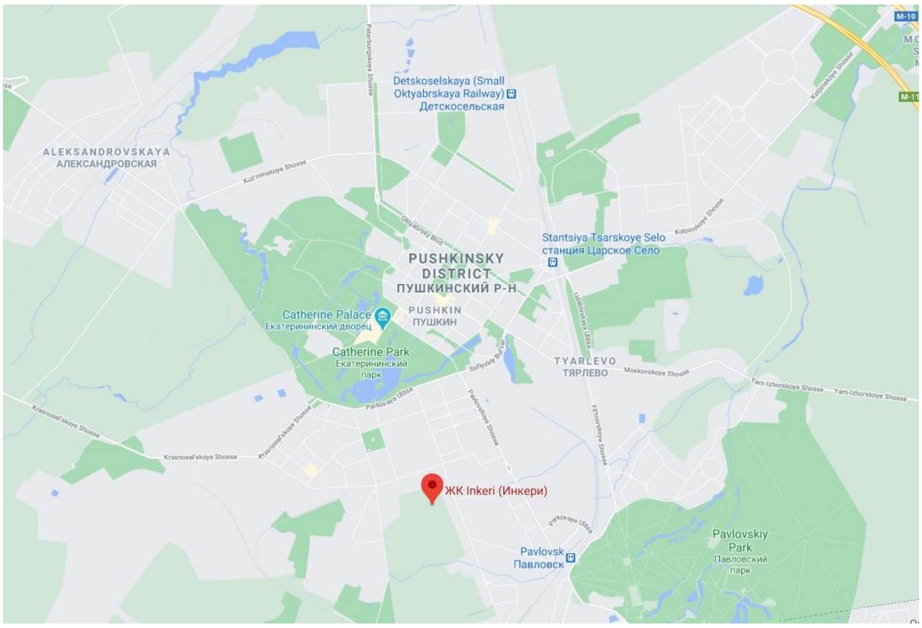

Figure 3.2 Map location of the “Inkeri” residential complex (Google Maps 2021).

The construction site for the “Novoorlovsky” residential complex is located on the Suzdal’skoe highway, to the north of the Novoorlovsky forest in the northern part of Saint-Petersburg. It is a part of an ongoing residential area development with further plans of expansion closer to the forest. The complex consists of a mix of high and low-rise residential buildings, parking buildings, a school and a kindergarten. The entire area is designed by the company, and one of the main goals in this project is to create a rationally planned residential area with streets, yards and infrastructure. The construction process of a 25-story building and a parking building has been carried out. Some materials between buildings do vary. For high-rise buildings precast concrete wall panels are used, while for the low-story buildings main structural walls are cast-on-situ with concrete and intermediate walls are constructed with aerated concrete blocks. The main material choice for the residential high-story building is as follows: concrete bored and driven piles, cast-on-situ concrete foundation grillage, concrete precast wall panels, cast-on-situ concrete floor slabs, rolled bitumen roofing, mineral wool plates for external thermal insulation. The energy efficiency of the residential building falls into the “B” category, meaning high.

The “Tarmo” residential complex is situated on Studencheskaya street in the northern part of Saint-Petersburg. Unlike the other projects, “Tarmo” is built around existing buildings, with implications on stricter carrying out of works in terms of technologies and compliance with norms according to interferences for neighboring buildings.

The residential complex includes five 11-story buildings and an adjoined parking building. The residential buildings share common material and technology choice. A combination of cast-on-situ and precast techniques is used in this project, thus a single building consists of both. The structural material choice for the houses is carried out as follows: concrete pile foundation, concrete slab foundation grillage, cast-on-situ concrete walls, precast concrete wall panels, brick external non-load bearing walls, expanded clay roof insulation, rolled bitumen roofing, mineral wool plates for external insulation. The energy efficiency class of the buildings is “A”, very high.

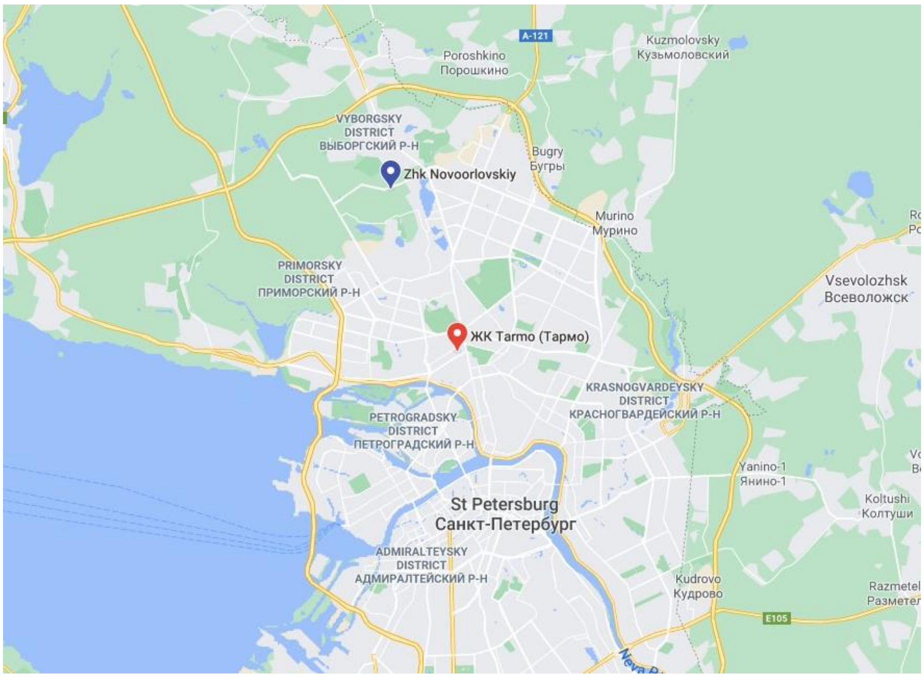

Figure 3.3 Map location of the “Novoorlovsky” and “Tarmo” residential complexes (Google Maps 2021).

3.3 Case study analysis and findings

The conducted construction site visits presented nearly all stages of construction. The tours were carried out trying to obtain as much background as possible in terms of the construction technologies used, material choice for different structural elements and other applications, work ethics and behaviors, work equipment, and other details, somehow connected to the topic of CWM.

The following findings are discovered through investigation of all stages of construction, seen fit for the research at hand, from groundworks and setting a foundation to the finalizing decorative works in apartments inside residential buildings. Because all main

stages of the construction process were examined, we are given a wider view on how the stages work with each other regarding waste generation, potential secondary uses of waste, waste collection and other. All three of the construction site tours were started from the administrative building on the site, first evaluating the cleanliness and organizational culture in the matter of littering and relation towards waste. Then, the tour advanced towards the earliest stage of construction, which at the site of “Inkeri” residential area happened to be foundation works, while on other sites the stages varied. At the “Novoorlovsky” residential complex construction site the first building process available for viewing was structural precast concrete wall assembly. And at “Tarmo” the casting of intermediate floor slabs was approached as the first process. During the visit special attention was given to waste collection at each viewed construction process. With the help of the
technical supervision it was determined who and where was responsible for the cleaning works and waste collection. Waste collection points and containers were examined in terms of location and waste sorting capabilities.

Administrative facilities

Starting from the administrative site headquarters a clean environment has been observed, though no sorting means are provided in terms of sorting containers, solid waste is always placed inside the collection points, showing a good level of organizational culture. In this fashion the work environment stays clean, showing an example for contractors and setting a reference for the workplaces on site.

Groundworks

Even though the ground preparation stage was not observed during the visits, ground piles and other natural material storages were discussed on site. During the ground preparation and excavation, the main waste being generated is solid dirt. From removing the soil layer, the fertile soil is reserved for later use in creating green areas around the streets and yards. The amount of saved fertile soil depends on its quality and the initial taken amount of soil usually exceeds later needs, thus excess soil is driven away from the construction site and disposed of. An interesting and unique practice was seen at the “Inkeri” site, where from the initial cleaning of the territory were saved and stored on the site natural boulders as a decoration on the finished residential streets. This practice is a good example of ingenious and effective use of otherwise useless and thrown away materials. Although it is unclear whether the decision has been made on the design stage or on the construction site itself, it is a valuable precedent for using existing natural features of the land for the benefit of the future construction. Excavated ground from the digging of pits is also stored on the site, unless the ground composure is clay, which is not suitable for backfilling. Saving and later using any amount of excavated soil and ground is crucial to reducing generated waste amount and it saves money for waste disposal.

Foundation works include the use of materials such as concrete, geotextile, waterproofing material and hard insulation. On the “Inkeri” construction site the process of casting a concrete foundation slab was observed. Although it is a common practice to bury small amounts of excess material as a backfilling, that was not observed on the site. Another important thing noticed at that stage is the safety barriers set around the excavated pit. It is noteworthy that on all the examined construction sites safety measures are being responsibly addressed, and the use of wooden barriers is a common occurrence on every stage of the construction. The safety barriers are constructed of wooden planks and as easily transported around the site as disassembled and assembled anew. Thus the safety barriers’ lifespan is only limited by the wooden planks lifespan, virtually lasting up until the end of construction. Not all barriers are reused and some are thrown away, which leaves room for improvement.

Figure 3.4 Reusable wooden safety barriers around a foundation pit

Frame construction

The main building frame consisting of walls and floor slabs is also of interest, because of the waste generation in the construction processes. The wall erection processes in the studied projects varied in regard to material and technology choice.

Seen at the “Novoorlovsky” site precast wall panel assembly creates less material waste than cast-on-situ, though provides more logistical effort. Cast-on-situ concrete walls are bringing about a number of potential waste emergences, from the framework to chipped away concrete due to poor casting quality.

At the “Tarmo” construction site, casting concrete walls is a less accurate method of wall erection than precast wall assembly, the mistakes in technology might spawn vertical deviations that may result in the need of wall trimming to meet the design measurements. Apart from that, formwork application is mandatory, and it being reusable, still has its lifespan and is due disposal at some point. As important as the other issues, steel reinforcement corrosion calls for a timely use and proper storage, creating more risks. Reinforcement, being metal is acknowledged to be a valuable resource and extra reinforcement is always sought after. Similar issues apply to the casting of concrete floor slabs as well. Some walls at the “Tarmo” residential houses utilize embedded concrete block areas that can be demolished in order to connect two apartments. This design solution is a good practice of forward thinking, as if should the need for such overhaul arise at the service stage, the total waste volume will be less and the works can be done more cleanly.

Figure 3.5 Demolishable wall design solution for apartment conjunction

Brick, concrete block, and aerated block walls, seen on the “Inkeri” and “Tarmo” sites are a place of waste generation. Material quality control has the power to prevent a significant amount of waste by declining block material of bad quality. To further minimize material waste workers of high skill are required, who would lessen the probability of wall disassembly due to poor quality of work.

Roofing

Bitumen roofings often used at the construction sites are another great example of a material with high recyclability potential, thus it is one of the prime candidates for separate collection and recycling. Roofing material for the “Inkeri” project was selected to be galvanized steel plates, which requires special skills for installation and the workers are scarce and highly skilled, thus using the material effectively, however metals are also a good candidate for recycling.

Figure 3.6 Galvanized steel plates roofing

Finishing works

Internal decoration works includes a significant number of construction processes and materials, as well as workers. This creates a tight workplace area with various contractors working in conjunction. Apart from the management difficulties of arranging finishing works in a productive “conveyor” manner, it spawns difficulties in cleanliness and waste management. In terms of better and more productive waste management and cleanliness maintenance finishing works are more efficient when done from the top floors to the bottom. As observed on all sites in question that is not always the case, as work is mostly always done in a hurry to catch up with the schedules, finishing works begin in some cases even before the walls and slabs of final floors of the building are erected. This creates additional hastle and mixing of waste from different contractors.

For some technological processes for finishing works, like tile installation, specific indoors conditions are needed. In the case seen in Figure 3.7 for temperature saving purposes openings in the outside walls are closed with boards and hard insulation. This practice spawns extra waste material, however rational application and reuse of these materials can negate the effect.

Figure 3.7 Openings covering for temperature control.

Although it is officially specified that each contractor must leave their workplace clean after they finished, that is not always the case. An interesting phenomenon occurs, as contractor workers from different organizations make verbal arrangements on site and distribute their responsibilities on cleaning and waste collection. This creates disputes over leftover materials on who should clean or collect them, sometimes resulting in half-cleaned floors as seen in the Figure 3.8. The waste generated at that stage includes various packaging materials mainly plastic, and other materials like metal, glass, plaster, ceramics. Another unnecessary waste occurrence comes from improper material storage. Many of the finishing works demand dry binders, and it is not uncommon to encounter a wet bag of plaster or other dry binder.

Figure 3.8 Unfinished cleaning of the workplace.

Figure 3.9 Unseparated waste collection from indoor cleaning.

Façade finishing

Façades of the buildings in all three of the residential complexes are so called “wet facades”. Mineral wool plates are attached to the external side of the outer walls, which is then covered by decorative plaster on a grid. What is important in this process is the storage of the dry plaster before the mixing, like mentioned previously in internal finishing works. Besides, the technological process of installation of the mineral wool plates implicates trimming of the plates, guaranteeing leftover mineral wool (Figure 3.10 below). A potentially advantageous idea has been brought up by the technical supervision representative to somehow separate the mineral wool from other waste and return it as a secondary material to be used in the production of mineral wool plates again. Unfortunately, there is no place to take such leftover materials to, which remains an issue for further thoughts. At the “Novoorlovsky” residential complex the façades also include closed balconies, where a good demonstrative design mistake can be spotted on the framework of the balcony (Figure 3.11 below). The design width of the balcony slab does not fit with the design size of the balcony framework. This was discovered only after the frameworks were delivered, so the decision was made not to dispose of the frameworks but in this case to ingeniously solve the issue by attaching steel profiles to the side of the balcony slab to support the balcony framework.

Figure 3.10 Unseparated mineral wool leftovers with other waste.

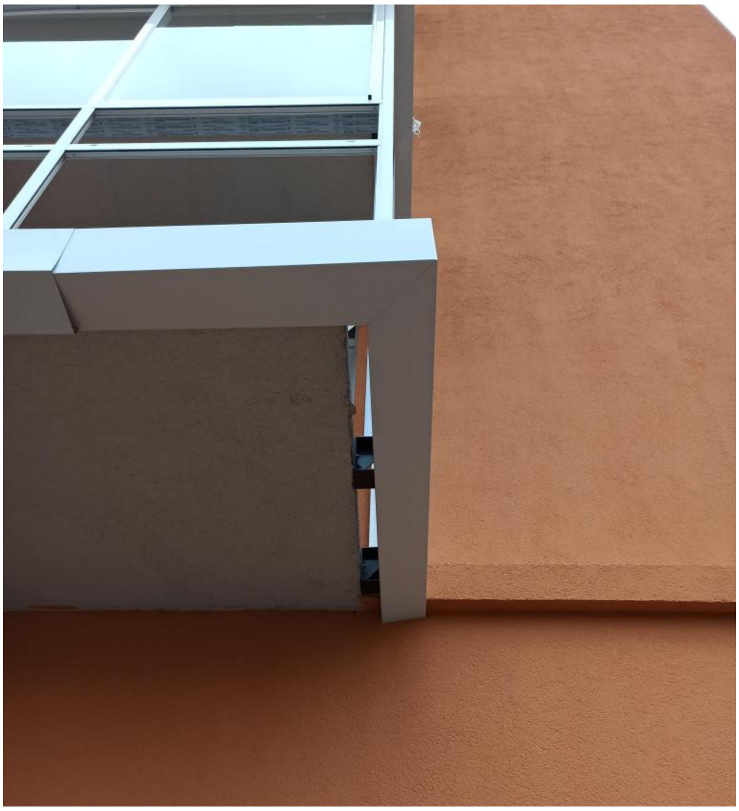

Figure 3.11 Steel profile solution to a balcony design mistake.

Figure 3.12 Container for unsorted waste collection.

Site organization

Another case, observed at the construction sites is the use of concrete slabs pavement for creating roads on site. The concrete slabs are a vital part for creating site infrastructure, and they are a valuable asset on every construction site. As noted by the technical supervision representative these slabs are heavily sought after, one such slab reused instead of bought new is a tangible cost saving. This way after finishing works on a site the slabs are usually quickly redistributed to other sites. However, the slabs are subject to heavy wear from heavy machinery driving on them and at some point they still need to be disposed of. Consisting of concrete and steel reinforcement, road concrete slabs are a potential source of steel and concrete stone.

Figure 3.13 Temporary material storage

Figure 3.14 Reusable scaffolding and questionable insulation storage

A significant part of any construction site is material storage areas, however sometimes materials are found stored wrongly. Seen on Figures 3.13 and 3.14 are bad examples of neglecting proper storage conditions and leaving mineral wool façade insulation in an open area. Such storage errors may make the entire material lose its insulating properties and render it unusable.

3.4 Monthly report analysis

Monthly reports of waste volumes were examined during the study. The reports (Appendix 2) consist of monthly tables of waste volumes in cubic meters per each project in Saint Petersburg and other cities of operation. The tables show volumes for construction and household waste together, and metal waste separately. The total waste volume amount is calculated and then the total waste weight is calculated using an estimated density index of 200. For the measured amount of waste disposal costs are also estimated roughly and factual costs are given at the end of a quarter. The measured comparison driving index is the volume of constructed buildings, hence the key performance indicator being tracked is waste volume per one cubic meter of a building. The reports serve as a valuable tool for monitoring waste generation tendencies and comparing the same project to itself in time, as well as between each other and projects between different cities. Figure 3.15 is a part of a diagram presentation report (Appendix 3.) comparing waste volumes and relations between cities of Saint Petersburg, Kazan, Tjumen and Jekaterinburg, and drawing the average for Russia.

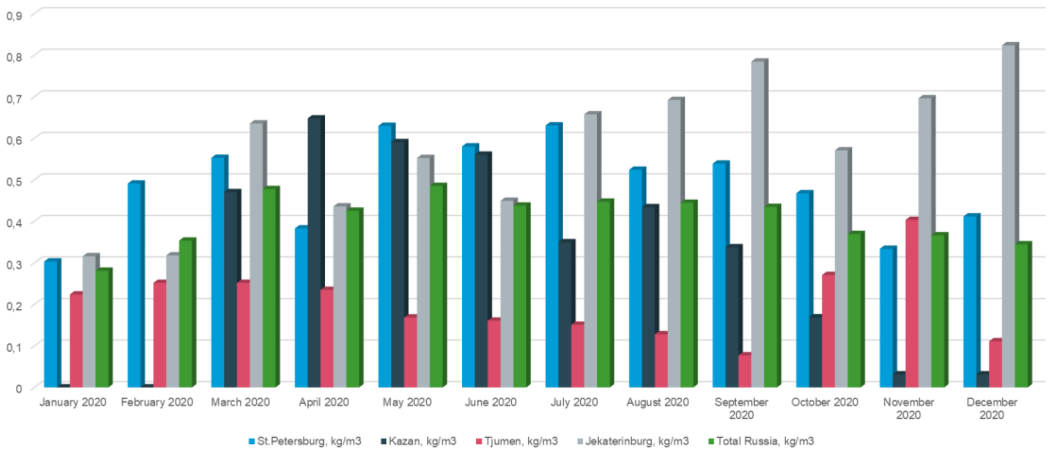

Figure 3.15 The ratio of the amount of waste per cubic meter building under construction, kg/m3.

As seen in the Figure 3.15, waste weight per cubic meter stays within comparability between the cities. Saint Petersburg is the biggest waste contributor due to the biggest volumes of construction. Fluctuations in other cities may be caused by varying stages of construction, thus it is safe to say that waste generation per building volume in the presented projects by cities is in similar condition.

3.5 Digital technology overview

BIM is used as a tool for coordinating the work of design institutes, providing fastest possible exchange of information, and is aimed at eliminating collisions between different information models of projects. The information model in the design is presented in the form of 2D / 3D documentation of the sections of the project ("AR", "KR", "IOS" and others). 4D form is presented in the construction organizational project containing a construction schedule. 5D is used in the form of a budget estimate. (Krylov 2019.) The structure and contents of design forms, as well as BIM objectives are shown in Figure 3.16 below.

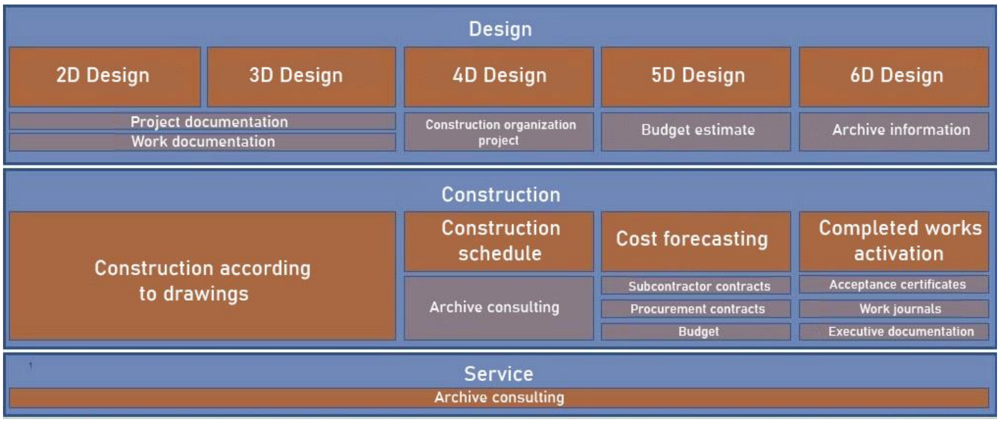

Figure 3.16 Information models of the design stages (project preparation), construction and service stage (adapted from Krylov 2019)

Work starts from creating a 3D model that is further filled by information about material choice for each element. The elements then are given each their own identification, depending on where it is installed, this is done by assigning a system aspect and class to each element, which shows for what task the element belongs, in what time frame it is installed, installation technology and cost. The identified elements then can be put into a table for producing documentation. This way all documentation is done with accordance with the initial model, which makes the whole process clear and less sustainable to collisions and deviations. This 5D BIM model is in use since 2015 and has proven to improve transparency, since all contract estimates, acceptance certificates, material bills and work orders are directly connected to the 3D design documentation. Apart from that, any change in the construction schedule is reflected on the project's financial index. The company also set a course on perpetual active innovation and modernization of tools. The implemented technology allows to "close" the BIM design cycle in terms of finding efficient and financially rational solutions. (Maltsev 2019, 147.)

YIT's BIM model in use since 2015 (Maltsev 2019, 145-146):

- 3D design by design organizations;
- Calculation work volumes in ITWO;
- Calculation construction costs in ITWO;
- Tracking the construction schedule in ITWO;
- Tracking physical completion in ITWO;
- Tracking and forecasting costs in ITWO;

Figure 3.17 Indication of completed work on a 3D model in ITWO
(project "Inkeri", Pushkin) (Maltsev 2019, 147)

Seen in the Figure 3.17 is a use case of the ITWO program for construction work completion tracking. ITWO is used for combining information streams into one place. It enables to make a dynamic connection between volumes,
schedules, real contracts and the work completions of contractors. (Maltsev 2019, 145.)

4 Results and suggestions for further development

4.1 Results

In the carried out research including visits to the projects of residential complexes “Inkeri”, “Novoorlovsky” and “Tarmo” it was studied how waste is generated on the construction site and how it is managed. By starting from the administrative facilities the importance of creating the right “atmosphere” on the site was noticed, and how the idea of maintaining cleanliness on the workplace is reinforced there. Although there were seen some not particularly well cleaned indoor areas, in general the construction site is maintained in a clean shape and waste is efficiently collected. Moving further through the sites, various technological processes were observed, it was noted how and why waste is generated in each of them. The main positive and negative points are displayed in the Table 4.1 below.

Table 4.1 Positive and negative observed practices

Waste origin	Positive points	Negative points	Comments
Administrative facilities	Clean work environment.	No waste sorting.	Lack of waste sorting is not as crucial, here waste would not classify as CW, but can set the aim for the whole site.
Groundworks	Use of natural features for later decorative purposes.	-	Example: At “Inkeri” boulders are used for street decoration.
Building frame	Use of precast elements; “Tarmo” embedded concrete block walls.	Cast-on-situ frame.	Precast structures result in less overall waste output, no need for formwork, fewer mistakes in construction.
Roofing	Bitumen roofing; Galvanized steel roofing.	-	Mentioned materials can be easily recycled.
Finishing works	-	Violations of the “top-to-bottom” work structure; Unclear cleaning responsibilities; Extra material loss from wall opening coverings.	“Top-to-bottom” work structure suggest finishing works to be done from top floors down for easier cleaning and waste collection.
Façade works	Balcony frame design flaw solution.	Mineral wool leftovers.	“Wet” facades guarantee mineral wool leftovers generation.
Site in general	Concrete slabs reuse; Wooden safety planks reuse; metal materials sorting.	Improper mineral wool material storage.	Reusing mentioned assets results in less unnecessary waste generation.
Design stage	Use of BIM in design and other stages.	-	BIM lessens the amount of design mistakes.

As of now no efficient waste sorting is done on site, apart from separating accessible metal and putting it up for sale. Construction waste on sites is gathered unseparated into same containers and then disposed by the waste contractor company. The waste handling contractor provides reports regarding the disposal of waste but means of disposal lie beyond YIT’s responsibilities. YIT construction sites present a high level of organization and subordination with good compliance with the safety requirements. Although responsibilities regarding waste collection and cleanliness maintenance are vaguely fixed officially, there is good potential for further development.

High level of worker control is a good advantage in promoting waste minimization and sorting. While other issues arriving from the waste contractor companies as there is virtually little to be done regarding proof of the legitimacy of waste disposal.

The main weaker CWM areas at YIT sites include lack of waste sorting in the administration facilities and other forms of worker education on waste sorting, using cast-on-situ design solutions, poor indoor cleaning and responsibility arrangements for contractors occupied with finishing works, improper material storage. These areas require foremost attention for improving waste management and implementing further developments. More thorough administrative control is required to address the mentioned issues.

The main ideas of proper CWM from the studied theoretical background are applicable in the studied cases:

- Waste avoidance through design, though is already practices still is not perfect, as the observed balcony frame issue shows that mistakes take place even with the help of BIM;
- Inert and non-inert waste separation could bring the benefit of partial waste disposal by backfilling;
- Material choice with less waste generation potential;
- Proper material handling and storage.

Construction scale may play a significant role in some areas of material sharing like mentioned with the wooden plank safety barriers and concrete pavement. With the increase of projects scale the amount of assets like these ones increases and this may make it harder to track them, resulting in loss and later unnecessary waste creation.

Studied reports show monthly unsorted waste amounts, costs for disposal and metal waste amounts. This information brings an understanding of generated waste amounts and the difference in waste generation between YIT projects in different cities. The values in these reports may serve as a background for further KPI (key performance indicator) development for better CWM evaluation.

CW situation in the Russian Federation is currently in a difficult position from the legislative side. The studied waste reports from YIT show that per city waste amounts are comparable. Judging by the involvement of YIT into the construction innovation sphere, their involvement into the scientific conferences, the company is one of the leading ones in digital technology use. By projecting the observed information on a wider scale, it should be safe to say that YIT's CWM representation may be average or above average in the country. While this is a guess, it is hard to get a defining picture on the situation. Following with this assumption, same principles of construction waste management development, that were suggested for the studied cases, are applicable at the wider scale.

4.2 Suggestions for development

Based on the theoretical background and the qualitative study of the construction sites a number of suggestions for CWM are proposed:

- Leaving room for ingenious solutions

Ingenious design solutions like the ones mentioned above (boulder decorative reuse, balcony fix) are not always obvious and such ideas can come from any worker, operating directly on site. Providing room for suggestions and possible rewards for outstanding or somewhat cost saving ideas can be a good motivation for increasing staff morale and raising overall positive waste management awareness.

- Purposeful waste management and staff education

Waste must only be sorted for a direct purpose, so not to be pointless work. Before setting up a sorting system on site, material streams must be arranged and specific materials needing sorting must be determined. Waste collection and sorting falls into the hands of contractor workers who are already responsible for cleanliness maintenance and waste collection. In such way an accessible educating program that shows the purpose and results of waste sorting can be decisive. As already noted, CWM culture starts from the administrative facilities, the headquarters of the construction site, this way the education must start from maintaining a clear goal orientation, setting examples for the rest of the site.

- Rational waste collection points placement

Reviewing where the waste containing materials of interest is originating is crucial for setting convenient collection containers. Poor placement of waste collection points may result in harmful work process disturbances, that may result not only in schedule delays but in unnecessary hassle on the workplaces.

- Establishing clear responsibilities

Clear responsibilities on cleanliness maintenance and waste collection are essential for effective waste sorting. Even though it is currently stated that each contractor must clean his workplace after he has finished the works, that is not clear enough on what waste must be collected or sorted. Clearly separating waste types needing to be collected can remove instances of dispute over who must clean what and is a first step towards effective waste collection and sorting on site.

- Proposals for setting industrial symbiosis agreements

Thorough study on different material type waste generation will create a background for elaborating on further developments for putting the materials to use. A test sorting period can be used to determine precise amounts of waste by material. Gathered information can be then processed to create research backed proposals for business collaboration or find new uses for materials.

- Cooperation between projects

Errors happen both at design and construction stage, these errors result in under or over-procurement. Creating a shared database of materials fit for supply or demanded on a site can bring about scenarios of live project-to-project interaction. The idea of such interaction is in easy material transportation between projects, in case if one project has some materials that can be useful in another one.

- IOT devices for material storage conditions monitoring

Some materials demand to be stored in specific conditions, dry places, out of direct sunlight or other. To ensure materials are stored correctly IOT sensors can be applied to selected groups of materials (1 sensor installation per storage unit of material). Such measure would prevent unnecessary material loss due to storage errors.

4.3 Key performance indicators

Key performance indicators (KPIs) are values for tracking and measuring effectiveness (Reh 2020). In modern economic world KPIs stand as a necessary tool for organizational management as they separate relevant information from irrelevant, make complex subject matters simpler and bring transparency (Meier et al. 2013, 100). According to Bawady et al. (2016, 48) business strategy often fail due to reasons such as an excessive amount of indicators, poor connection between indicators and business objectives, lack of strategic focus on selecting KPIs, and lack of understanding of the performance measures. Keeping this in mind it was decided to keep KPIs simple, understandable and objective oriented.

When planning for future optimizations or changes it is always essential to track the progress and evaluate success. The obvious indicator of successful waste management is the decrease of waste by volume or weight. Anyhow, CWM development includes not only the prospect of reducing generated waste, but also finding new uses for the materials hidden within. These new uses offer business opportunities and in such a way measuring only waste volume reduction is not sufficient. Waste management deals with several stages like waste sorting, removal, disposal and often the final numerical values are known post factum, that’s why lagging indicators are suitable in this case. In other words, the suggested KPIs are intended for measuring values and subsequently evaluating effectiveness from the past periods. From the gathered theoretical knowledge and according to the stated suggestions the following KPIs are proposed:

- Gained value

$$\frac{Total\ earnings}{Total\ initial\ waste\ volume}\text{, rub/m}^3 \qquad (4.1)$$

Gained value (4.1) is total earnings from waste divided by the total initial waste volume in rubles per cubic meter. The total initial waste volume is the volume of all waste before further waste redirections. Earnings are made from redirecting waste streams, selling materials derived from waste or selling products made from said materials. The indicator shows the added value to waste and serves as an index of successful business symbiosis establishment.

- Saved value from disposal

$$Total\ cost\ of\ initial\ volume\ disposal\ - Total\ factual\ cost, \text{ rub} \qquad (4.2)$$

Saved disposal value (4.2) is a sum of saved costs on disposing waste in rubles. It is calculated by subtracting the factual paid disposal costs from assumed disposal costs for all waste. By taking the initial waste volume before waste material redirecting for reuse, recycling or recovery, the disposal cost is assumed with accordance with the waste contractor pricelist. This assumed value serves as a point of comparison. The total factual cost is what is actually paid for the disposal. Thus the difference between these numbers is the saved value from preventing unnecessary waste disposal. This indicator is an index of effective waste material recovery and redirection.

- Waste disposal volumes to initial waste volume

$$\frac{Total\ factual\ volume}{Total\ initial\ waste\ volume} \qquad (4.3)$$

Waste disposal volume to initial waste volume (4.3) is calculated by dividing the total factual disposed volume of waste by the initial waste volume, and it is measured in rubles per cubic meter. The total factual volume is the actually disposed waste. The total initial waste volume is measured before waste material redirecting for reuse, recycling or recovery. The indicator is similar in the target to the saved value from disposal (4.2.) indicator, however is not tied to the variability of disposal prices. It is more suitable for inter-project comparisons, apart from progress tracking within the same project.

- Procurement errors by area

$$\frac{Underprocurement + Overprocurement}{Built\text{-}up\ area} \qquad (4.4)$$

Procurement errors by area (4.4) is the sum of all instances of under-procurement or over-procurement, divided by the built-up area. The division by built-up area is done for inter-project comparison purposes. The indicator reflects the number of design and other mistakes resulting in procurement errors, this way tracking the effectiveness of waste management at the design level.

5 Discussion

After conducting the construction site tours, waste reports and company's publications a qualitative representation of the CWM was created. The main research questions were answered, although the last one not to a satisfactory degree. The first and the second research questions revolved around YIT's construction sites and possible development ideas. Based on the studied background theory, development directions were set. In addition to this, separate new ideas were brought up. To track the development of CWM, a number of KPIs were also suggested. The third question was answered roughly, by extrapolating observed YIT cases on the entire construction sector. For the more precise answer, a wide and more thorough research is needed by comparing the situations in various companies and cities.

Regarding the first and the second question, the provided suggestions and KPIs, many of the suggestions require further research and work to be proven useful and implemented in life. For example, the logical continuation for the rational waste collection points placement would be a research on types of waste that is of interest to us, where is it generated, how to implement the idea to minimize workflow disturbance and to fit the workers. The suggestions are mostly for optimizing waste management through on-site ways. Suggestions regarding waste sorting foremost require an accepted strategy as to where the material derived from waste is going. This means that before starting work on the mentioned developments, there must be found an organization for receiving the materials and utilizing them, for example.

The proposed KPIs are mostly based on already tracked information, this way it would not require much restructuring to adapt to them. These KPIs are designed with the intention to create trackable values for progress evaluation within the same project or between different projects.

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Appendix 1. Interview topics

Thematic interview topics, discussed with the head of technical supervision at YIT construction sites:

- Organizational culture
- Contractor responsibilities
- Special practices of material reuse

Appendix 2. Construction waste removal tables. January – December 2020. Saint Petersburg, YIT

January 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", январь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металл, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 - Пушкин (Inkeri)	15	143,3	132045	0,0011
Объект 0149 Суздальское шоссе (Novoorlovsky)		102,82	123245	0,0008
Объект Студенческая,24 (Tarmo)		297,9	103793	0,0029
Итого, куб.м	15	544,02	359083	0,0016
коэффициент		200		
Итого, кг	*****	**108804**		
*~ Затраты, тыс.руб *****	**	*510*		

February 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", февраль 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 - Пушкин (Inkeri)		326,6	132045	0,0025
Объект 0149 Суздальское шоссе (Novoorlovsky)		118,06	123245	0,0010
Объект Студенческая,24 (Tarmo)		436,3	103793	0,0042
Итого, куб.м	0	880,96	359083	0,0025
коэффициент		200		
Итого, кг	*****	**176192**		
*~ Затраты, тыс.руб *****	**	*820*		

March 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", март 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 - Пушкин (Inkeri)		306,6	132045	0,0023
Объект 0149 Суздальское шоссе (Novoorlovsky)		294	123245	0,0024
Объект Студенческая,24 (Tarmo)		499,6	148297	0,0034
Объект 0803-Э Горелово		15		
Итого, куб.м	0	1115,2	403587	0,0027
коэффициент		200		
Итого, кг	*****	**223040**		
*~ Затраты, тыс.руб *****	**	*1000*		

* - количество вывезенного металла в кг отражается в универсальном передаточном документе, предоставляемом подрядчиком в конце месяца, следующим за отчетным.
** - оплата за вывезенный подрядчиком металл производится им в соответсвии с количеством, указанном в универсальном передаточном документ
*** - количество вывезенных отходов по категориям определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.
**** - точная сумма затрат определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.

Appendix 2. Construction waste removal tables. January–December 2020. Saint Petersburg, YIT

April 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", апрель 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 - Пушкин (Inkeri)		286,6	132045	0,0022
Объект 0149 Суздальское шоссе (Novoorlovsky)		212,1	123245	0,0017
Объект Студенческая,24 (Tarmo)		273,28	148297	0,0018
Объект 0803-Э Горелово				
Итого, куб.м	0	771,98	403587	0,0019
коэффициент		200		
Итого, кг	*****	**154396**		
*~ Затраты, тыс.руб ******	**	*680*		

May 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", май 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 - 2 Пушкин (Inkeri)	15	403,3	67181	0,0060
Объект 0196-72 - 3 Пушкин (Inkeri)		283,3	67181	0,0042
Объект 0149 Суздальское шоссе (Novoorlovsky)		340,82	123245	0,0028
Объект Студенческая,24 (Tarmo)		250,48	148297	0,0017
Итого, куб.м	15	1277,9	405904	0,0037
коэффициент		200		
Итого, кг	*****	**255580**		
*~ Затраты, тыс.руб ******	**	*~ 1000*		

June 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", июнь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)	1500 кг	633,2	134362	0,0047
Объект 0149 Суздальское шоссе (Novoorlovsky)		362,2	123245	0,0029
Объект Студенческая,24 (Tarmo)		182	148297	0,0012
Итого, куб.м	0	1177,4	405904	0,0030
коэффициент		200		
Итого, кг	*****	**235480**		
*~ Затраты, тыс.руб ******	**	*~ 950*		

* - количество вывезенного металла в кг отражается в универсальном передаточном документе, предоставляемом подрядчиком в конце месяца, следующим за отчетным.
** - оплата за вывезенный подрядчиком металл производится им в соответсвии с количеством, указанном в универсальном передаточном документ
*** - количество вывезенных отходов по категориям определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.
**** - точная сумма затрат определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.

Appendix 2. Construction waste removal tables. January–December 2020. Saint Petersburg, YIT

July 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", июль 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)	3100 кг	396,5	134362	0,0030
Объект 0149 Суздальское шоссе (Novoorlovsky)	4100 кг	539,02	123245	0,0044
Объект Студенческая,24 (Tarmo)	1000 кг	214,04	106946	0,0020
Итого, куб.м	0	1149,56	364553	0,0031
коэффициент		200		
Итого, кг	*****	**229920**		
*~ Затраты, тыс.руб *****	****	*~ 1000*		

August 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", август 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)		332,3	67181	0,0049
Объект 0149 Суздальское шоссе (Novoorlovsky)		230,73	126865	0,0018
Объект Студенческая,24 (Tarmo)		225,36	106946	0,0021
Итого, куб.м	0	788,39	300992	0,0030
коэффициент		200		
Итого, кг	*****	**157678**		
*~ Затраты, тыс.руб *****	****	*~ 1150*		

September 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", сентябрь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)		416,5	67181	0,0062
Объект 0149 Суздальское шоссе (Novoorlovsky)		315,73	150973	0,0021
Объект Студенческая,24 (Tarmo)	1000 кг	256,98	149095	0,0017
Итого, куб.м	0	989,21	367249	0,0033
коэффициент		200		
Итого, кг	*****	**197842**		
*~ Затраты, тыс.руб *****	****	*~ 1250*		

* - количество вывезенного металла в кг отражается в универсальном передаточном документе, предоставляемом подрядчиком в конце месяца, следующим за отчетным.
** - оплата за вывезенный подрядчиком металл производится им в соответсвии с количеством, указанном в универсальном передаточном документ
*** - количество вывезенных отходов по категориям определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.
**** - точная сумма затрат определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.

Appendix 2. Construction waste removal tables. January–December 2020. Saint Petersburg, YIT

October 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", октябрь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)		373,2	67181	0,0056
Объект 0149 Суздальское шоссе (Novoorlovsky)		305,9	150973	0,0020
Объект Студенческая,24 (Tarmo)	2000 кг	178,92	149095	0,0012
Итого, куб.м	0	858,02	367249	0,0029
коэффициент		200		
Итого, кг	*****	**171604**		
*~ Затраты, тыс.руб *****	****	*~ 1250*		

November 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", ноябрь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)		209,9	67181	0,0031
Объект 0149 Суздальское шоссе (Novoorlovsky)		180,73	150973	0,0012
Объект Студенческая,24 (Tarmo)	1000 кг	222	149095	0,0015
Итого, куб.м	0	612,63	367249	0,0019
коэффициент		200		
Итого, кг	*****	**122526**		
*~ Затраты, тыс.руб *****	****	*~ 1050*		

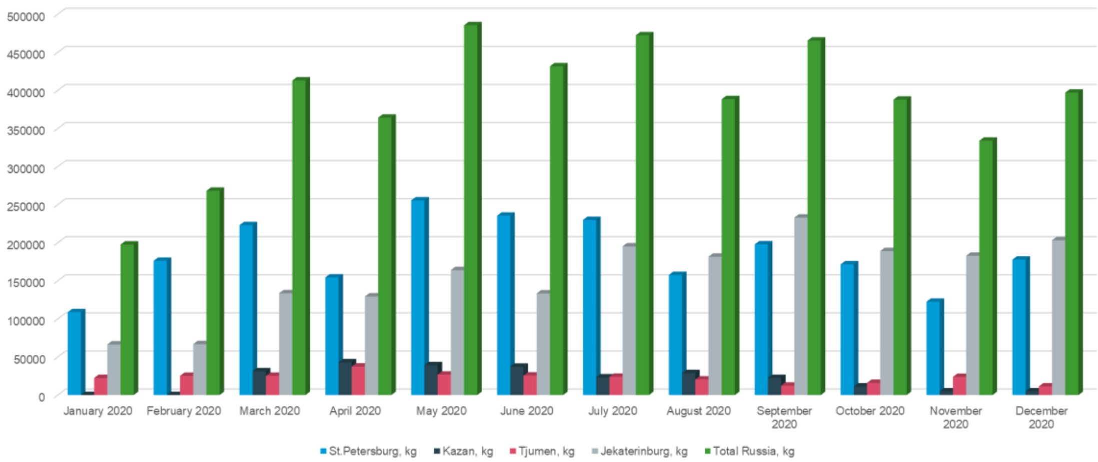
December 2020:

Таблица вывоза отходов со строительных объектов АО "ЮИТ Санкт-Петербург", декабрь 2020 года				
Объект	**Кол-во вывезенных отходов *****		**Объем строящихся зданий, куб.м.**	**Соотношение количества отходов на куб.м. строящегося здания**
	металлом, куб.м	**отходы строительства и бытовые отходы, куб.м**		
Объект 0196-72 Пушкин (Inkeri)		253,2	132045	0,0019
Объект 0149 Суздальское шоссе (Novoorlovsky)		394,73	150973	0,0026
Объект Студенческая,24 (Tarmo)	1000 кг	241,1	149095	0,0016
Итого, куб.м	0	889,03	432113	0,0020
коэффициент		200		
Итого, кг	*****	**177806**		
*~ Затраты, тыс.руб *****	****	*~ 1500*		

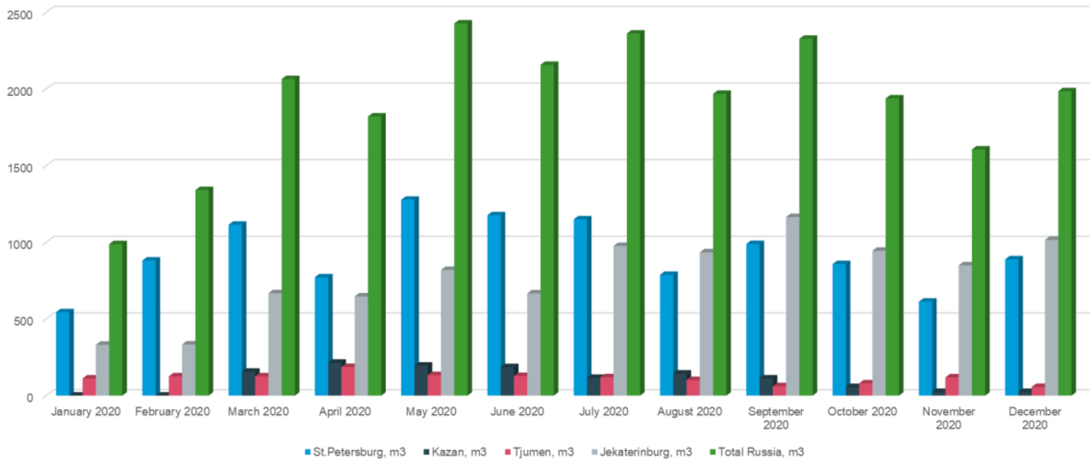
* - количество вывезенного металла в кг отражается в универсальном передаточном документе, предоставляемом подрядчиком в конце месяца, следующим за отчетным.
** - оплата за вывезенный подрядчиком металл производится им в соответсвии с количеством, указанном в универсальном передаточном документ
*** - количество вывезенных отходов по категориям определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.
**** - точная сумма затрат определяется в конце квартала на основании документов, предоставляемых с полигонов, на которые вывозятся отходы.

Appendix 3. Waste reporting, YIT Housing Russia. January–December 2020

The amount of waste removed from construction sites, kg

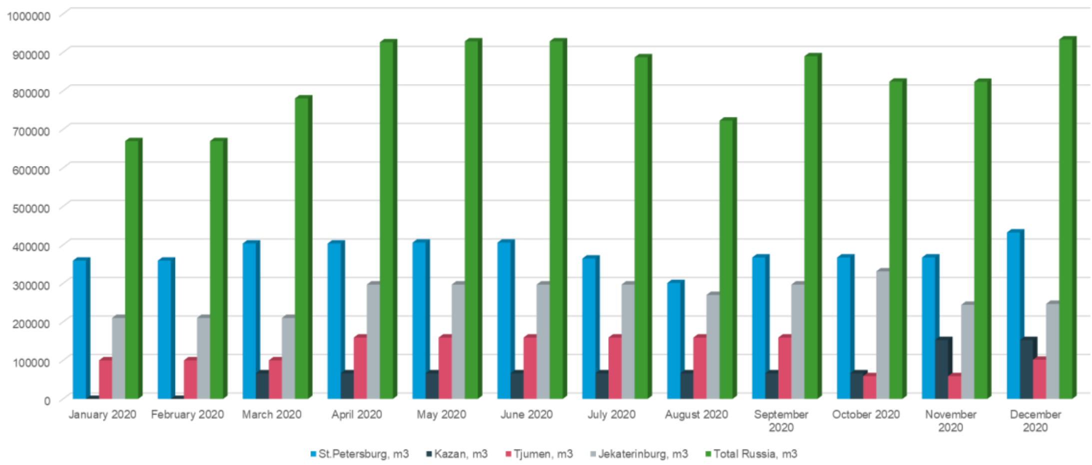


The amount of waste removed from construction sites, m3

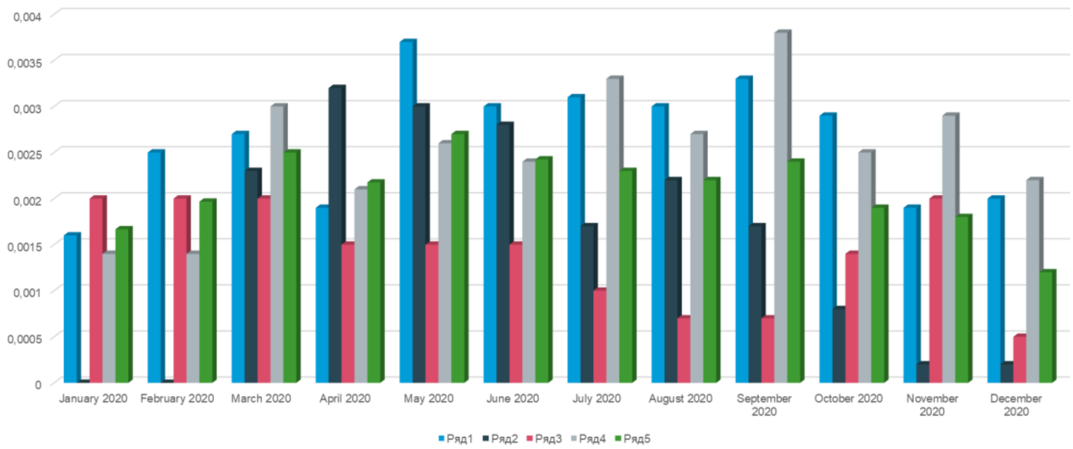


Appendix 3. Waste reporting, YIT Housing Russia. January–December 2020

Volume of buildings under construction, m3



The ratio of the amount of waste per cubic meter building under construction, m3/m3



The ratio of the amount of waste per cubic meter building under construction, kg/m3