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Construction Projects' Waste Prevention and Expected Minimization of Cost and Environmental Impacts through Adopting a Comprehensive System for Document Management

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Waste originating from construction projects is the major source of pollution amongst all industrial sectors in the European Union (EU) as well as globally. It is estimated that more than 35% of all disposed waste in the EU has been a by-product of building activity. This significant loss of materials hinders project profitability, reduces competitiveness of companies involved in such projects and causes considerable environmental burden. An acceptable level of waste is inevitable; however, there are possibilities to minimize the waste through amendments of reducing problematic executive procedures. One of the most important reported factors that increase waste is ineffective document management that may lead to inadequate communication throughout the construction project. As such, the present paper focuses on estimating the possible environmental and economic benefits if a proper document management system is applied on construction projects. The research steps include the approximate calculation of the operational project cost, the volume of material waste related to inadequate information systems based on statistical data and the calculation of benefits from the establishment of adequate information systems using measurable indices. The findings suggest that significant waste reductions are feasible and that the volume of solid construction debris that usually ends up in landfills can be greatly reduced. The actual debris in every skip bin could be reduced to approximately two-thirds of the currently produced volume, for every 100 square meters (m^2) of an industrial building floor area. Besides, the debris volume in a skip bin could be reduced to more than half of the currently produced volume for every 100 m^2 of public and commercial retail building floor area.

Keywords: construction project management, document and information management, resource efficiency, reduction of environmental impact, waste prevention.

Introduction

Statement of the problem: production of excessive material waste and its link to improper document management in construction projects

Significant social and legislative progress has been made in the EU to reduce different kinds of waste such as plastic or construction waste; however, there is still significant potential of improvement (Papaoikonomou et al., 2018). Construction projects are particularly susceptible to production of material waste throughout their entire life cycle. The cost of such wastage can amount to 15% of the project's budgeted cost. To consider the material loss related to construction, early studies suggest that the amount of landfilled debris from new construction projects and demolition works is reaching at least one-fourth of the total volume disposed, with the rest originating from other sources (Wyatt, 1978; Skoyles and Skoyles, 1987).

The total percentage of material loss in construction sites has been estimated to be approximately 10% of total supplies delivered for the entire project (Egan, 1998). Studies in the EU suggest that an average of 13% of the raw materials present in every site shall be thrown away unused (RES, 2017). In some cases, the economic cost of waste can reach approximately 30% of the overall assigned budget for project materials (Fadiya et al., 2014). Materials landfilled or buried in earthworks originating from discarded building inventory represent two to three out of every five cubic meters (m^3) handled (Ganguly, 2012).

Environmental considerations among citizens in Europe for less waste in conjunction with stricter environmental laws in the EU have been shaping EU legislation since as early as 1996 (Trevorrow, 1996). The EU has increasingly imposed stricter regulations (EC, 2008; EC, 2019a), mainly for two important reasons. The first reason is the magnitude of waste that originates from building activity. Waste from construction and demolition (CandD) represents 35% of all waste across the EU, a volume of over 450 million metric tons (tn) generated every year. The second reason is the additional environmental impact associated with the consumption of valuable resources in order to accomplish construction projects: energy, building materials and water are necessary to complete every stage of construction. The European Waste Framework directive aims at increasing the level of recovered, recycled and reused wasted materials to a strict minimum of 70% and CandD waste is categorized as a priority waste stream (EC, 2023). The volume of materials that are recovered or recycled from CandD waste is still highly variable and unacceptable in some cases, with certain countries presenting only less than 10% of the total volume produced (Interreg Europe, 2022).

In order to maximize inventory efficiency and to reduce the environmental and social consequences of waste, waste management guidelines have been included in the amended Waste Directive (EC, 2019a) prioritizing prevention of waste as the most critical factor to be considered, allowing landfill of materials only as the last option, when every other option has been tried. Policies applied demand a reduction of generated waste by imposing tax penalties and bans (EC, 2019b). Active companies in the building sector have thus to adopt methods and systems promoted by the European Circular Economy Action Plan (EC, 2020) that shall reduce the production of waste, and shall forward the circular transformation of the industry.

By reducing material waste, building firms can minimize production costs, improve their operations environmental impact and benefit from a competitive position improvement (Faniran and Caban, 1998). Hindering factors that pose important adversary trends, however, exist, which include poor on-site waste records and consequently inconsistent reports on cost of waste (Seydel et al., 2002). As a result, there are inconclusive cost estimates for proper waste disposal, while company policies and methods may be unable to combat these problems. Sustainable waste management policies, especially implementation of waste prevention methods, may be inexistent when there are no obvious or proven financial gains, and they may be dismissed as unnecessary further economic weight (Graham and Smithers, 1996).

Document mismanagement and the correlation to materials waste

Many construction sites do not store important data in a consistent and efficient way, making access to critical

information difficult and forcing team members to manually re-enter that data on a regular basis (Howell, 1999). Existing document management systems (DMS) may still employ the circulation of printed material with insufficient or outdated information, leading to omissions and mistakes. Acquiring correct project data in printed or digital form consumes an approximate 13% of construction personnel working hours, even in current projects (KPMG, 2017). It has been estimated that unused data in the building industry amounts to over 95% of all data generated in every firm (Hill, 2017). In construction works, valuable information is usually transmitted simultaneously in linear parallel data flows, thus excluding parties from accessing important information quickly, increasing the occurrence of rework and resulting to waste (Lee et al., 2002). Approximately 90% of the files employed in building sites are not structured or properly indexed and an estimated three out of ten construction firms are using information technology (IT) systems that do not facilitate direct file exchange between them and data should be re-entered (Hill, 2017). This practice forces a multitude of digital and paper documents to circulate simultaneously on site among project participants and firms, including specifications, building plans, emails and fax messages, customer correspondence and demands creating a confusing mixture of valid and invalid information (Snyder et al., 2018).

As such, a well-operating information system can greatly improve the prevention of rework and waste, by an estimated 15% on the total cost of a project (Blackwell, 2017). There are also significant reductions in the cost of quality during the construction phase that can be achieved by focusing on improving information and document transmission at the initial project stages, thus greatly improving the team's output (Love et al., 1999).

Waste related to poor document management is an important factor that should be addressed by construction firms because of its association with the continuous generation of unnecessary waste. In order to minimize the economic and environmental burden caused by CandD waste, the improvement of information management through proper document dissemination is a critical factor (Blackwell, 2017). A certain amount of unavoidable waste shall be produced throughout every building project, but research demonstrates that in order to minimize avoidable wastage the principal causes which increase that wastage should be considered. Studies suggest that not only is there a strong correlation between inadequate communication and the phenomena of rework and material wastage, but also with efficient project performance and the presence of a capable documents administration system (Lee et al., 2005). Absence of a thorough document management system is reported as the main reason for waste generation on-site that could have been prevented. Poor project communications amplify the amount of generated waste and project profitability can be greatly improved by the minimization of administrative costs, shorter production timeframes and the termination of avoidable repeat work and material waste by introducing IT-centered communications (Love and Li, 1999; Paulson, 2000; Blackwell, 2017).

For a construction document management system to handle information effectively, all the details needed to manage the project technically and financially have to be included. Technological advances in information technology allow the digitalization of all necessary documents that were previously circulated in a paper form, into digital files that can be saved and stored. Thus, a document, in project management terms, is defined as a digital container file which can combine data of different formats (plans, spreadsheets, text, images or even multimedia files) from many different sources, focused on a particular topic (Björk, 2001) in order to meet the needs of a project team member or stakeholder.

In the present research, the proposed approach for a solution that reduces the material wastage related to information mismanagement is the investment on a coherent DMS. The method of approach adopted includes the following stages: a) demonstration of the correlations between poor document management and waste production through supporting literature review, b) approximate calculation of the volume and cost of materials waste related to inadequate information systems based on statistical data, c) quantification of benefits by the utilization of a coherent DMS, using measurable indices and d) discussion. Since the building industry is the main source of landfilled waste and the magnitude of cost associated with the procedures of disposal, the amount of wasted materials that can be saved on a global scale is important, as it represents substantial financial and environmental gains.

Methods

Current practices and estimated amount of information disseminated in construction projects

Augmentations in budget distributed for evaluation and prevention of errors will not be expressed by a reduction of failure costs immediately, because of the time lag between cause and effect (Campanella and Corcoran, 1983). Through reductions in the causes of waste and rework, an important downgrading in cost of appraisal and incidental expenses will occur (Low and Yeo, 1998). Works and materials are pre-evaluated by the main contractors and subcontractors, in most types of contracts, after the initial plans and specifications have been approved by the developer. Only 50% of the data which is required to suitably appreciate costs is available in early plans for bidding contractors to prepare their offers (Lyra, 2010).

The execution of flawless IT document management is essential because of the huge amount of information which is exchanged at the time of construction projects: an average of 55,000,000 documents might be required in big infrastructure projects, which will be delivered through 130,000,000 messages, printed material and emails in 12 million workflows (Famous, 2018). As such, by the year 2000, IT was the biggest capital expense in the construction business (Carter et al., 1999). It was estimated that firms which systematically applied IT systems for data dispensing among various project stakeholders significantly minimized the time required to process and finalize administrative tasks (Davidson and Moshini, 1990; Baldwin et al., 1996).

Correlation between types of waste in construction and poor coordination in documents management

The definition of waste is the deviation between ordered materials and those which are actually delivered during final hand-over (BRE, 1981). However, separating physical losses from monetary losses is important. In some cases, from a solely financial point of view, wasting materials is cheaper than trying to prevent production of waste (Skoyles and Skoyles, 1987) and some waste is often inescapable.

In general, there are two main categories that can be especially addressed in relation to document management. These are financial and environmental costs associated with the building procedure (Ward et al., 1991): operational waste and volume of construction waste which can be defined as the amount of money which is lost and the volume of materials which is wasted because of change orders and the cost to manage further/additional information requests (F/AIRs) per m^2, respectively (Lyra, 2010).

Even though a lot of construction drawings and technical documents are made available in a digital form from the very start, a big percentage, though created in color, is still distributed in black and white photocopied format. The main reasons for this practice include the color printing cost, the attempt to make document dissemination easier for low-technology companies or to create a sense of standard procedure. Research suggests (LePatner, 2008) that a lack of high-definition drawings and the absence of color details increase ambiguity and waste, a form of waste specifically related to the absence of adequate documentation. Thus, productivity improvements and reduction of material waste would be experienced by timely access to the latest and most revised forms. This can be partly achieved by accessing color documents, diagrams and drawings in high resolution, through an IT system, on computer screens and mobile devices and with only a supplementary percentage delivered in a printed form.

There have been findings in an analysis on construction waste using two estimating approaches, which conclude that insufficient documentation and poor document communication shape the most important and severe reasons for waste production (Halttula et al., 2017). These problematic issues result in delays in delivery of project parts, which in turn lead to the economic burden of clauses, the waste of materials, man-hours and staff expecting information or constructing with the wrong specifications, the necessity for repairs and dismantling, not to mention disagreements on liability errors which are caused by revisions that had not been conveyed in a correct or timely manner (LePatner, 2008).

The following steps are analyzed here: 1) estimation of general waste volume in construction/demolition projects and estimation of the corresponding monetary cost according to bibliography, 2) estimation of the percentage of the aforementioned factors associated specifically with poor document management and poor document quality, and 3) calculation of possible

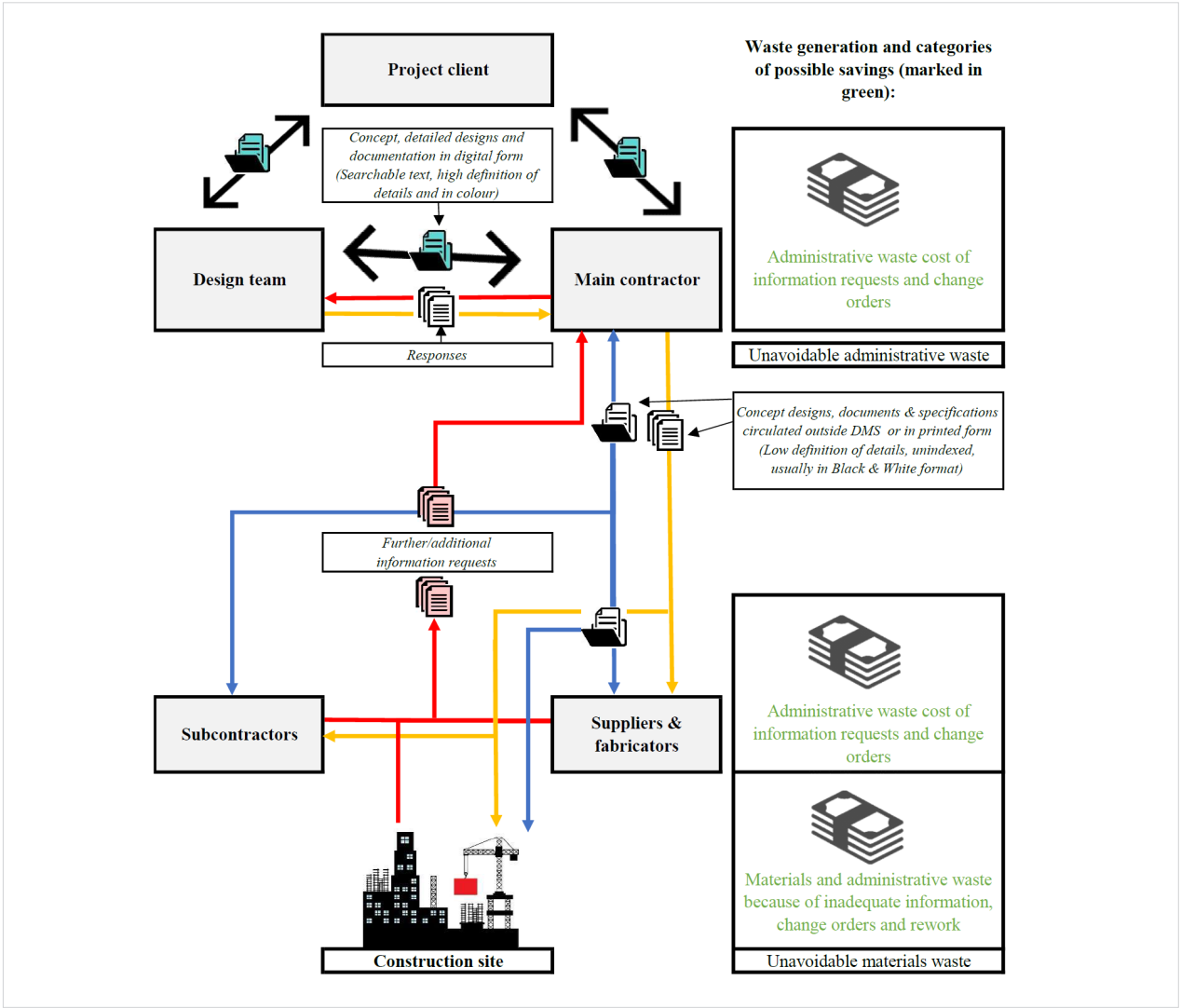
savings as a percentage over these figures, after the application of a Document Management System (DMS). In order to keep these estimations realistic, the minimum bibliographic value of possible benefits is applied on all calculations.

Results and Discussion

Estimated savings expected in operational waste cost

The economic and environmental costs which are involved in the waste of materials in the construction sector amount to between 10% (Egan, 1998) and 30% (Fadiya et al., 2014) of the final cost of each construction project. In order to narrow down this percentage to quantify only the cost of operational waste linked to mismanagement of documents specific indicators that are directly measurable in terms of cost are used. Thus, the indicators to calculate operational waste are related to the number (instances) as well as the cost of F/AIRs, document reviews and changes in the quantities of material. *Fig. 1* demonstrates the main document flows between project team members and stakeholders in a typical construction project, the main categories of waste and related possible savings that can be achieved by the implementation of a DMS.

Fig. 1. *Document flows in typical construction projects and categories of possible savings in waste that can be achieved by the implementation of a DMS*



According to Gallaher et al. (2004), approximately 0.96 euros per square meter (€/m^2) is spent by the contractors of a project for the management of F/AIRs during the design and costing period of the offer and 1.28 €/m^2 during the construction period (*Table 1*). It is estimated that the additional administrative cost for managing the revisions of technical documents during the construction period is around 2.56 €/m^2. These values are presented on Column (A) of *Table 1*. An expected percentage of F/AIRs linked to poor document management reaches 1 out of 4 of the total requests (25%) or even 1 out of 2 (50%), depending on the type of a construction project (Lyra, 2010). Alterations made by the client afterwards, changes made because of specifications and regulations or construction parameters, as well as omissions or design and writing errors of technical documents and drawings will be excluded by this assumption, because they cannot be prevented by the DMS.

A realistic reduction in material waste which results from the implementation of a consistent DMS is set to the minimum estimation of 10% in terms of cost of operational waste according to Egan (1998) and Lyra (2010), displayed in column (B) of *Table 1*. The decrease in waste is because of the expected minimization in the number of F/AIRs that are necessary for the successful pre-designation and construction of the project and consequently to the man-hours required by the staff to be processed. Furthermore, the benefit arises from the more accurate measurements, ordering and placement of materials in the construction project and so the handling and maintenance of smaller stocks and materials. Revisions due to a lack of a coherent DMS, according to Lyra (2010), constitute respectively 25% [row (iv) in *Table 1*] to 50% [row (v) in *Table 1*] of the total changes in design and specifications. Thus, the total monetary benefit may range from 0.29 €/m^2 (10% of the value (vi) in *Table 1* below) to 0.35 €/m^2 (10% of the value (vii) in *Table 1* below). This benefit can be considerable for large construction sites, as it varies between 28.77 €/100 m^2 and 35.16 €/100 m^2.

Estimated reductions expected in environmental impact by reducing the volume of waste

It is estimated that up to 10% of the weight of all materials meant for the construction of a project, ends up being discarded (Bossink and Brouwers, 1996). This percentage incorporates unpreventable waste related to the construction difficulty and the method used as well as waste of materials related to the lack of coordination and management of documents and information. Furthermore, 1 in 5 (20%) to 3 in 10 (30%) of the volume of materials ordered to be sufficient in project needs is not handled properly and thus ends up being rejected (Hassan et al., 2020). These percentage estimates are confirmed by the resulting financial waste. The financial burden of waste materials is also up to

Table 1. *Operational processes in building project management and the expected cost of waste per m^2 of a final constructed area in comparison to the estimation of possible monetary savings after applying a coherent document management*

Building project operational processes	(A) Cost of waste per m^2 of construction without a cohesive document system	(B) Monetary savings per m^2 of construction after applying a suitable document system
Administration of further/additional information requests while the project is in the phase of design (i)	0.96 €	0.10 €
Administration of further/additional information requests during the phase of construction (ii)	1.28 €	0.13 €
Administration of all incurring change orders during the phase of construction (iii)	2.56 €	0.26 €
Administration of change orders (est. minimum) related to inadequate document administration (iv) = 0.25 x (iii)	0.64 €	0.06 €
Administration of change orders (est. maximum) related to inadequate document administration (v) = 0.50 x (iii)	1.28 €	0.13 €
Minimum anticipated total waste per m^2 of construction (vi) = (i) + (ii) + (iv)	2.88 €	0.29 €
Maximum anticipated total waste per m^2 of construction (vii) = (i) + (ii) + (v)	3.52 €	0.35 €

30% of the cost of materials though the volume of waste materials is not always in direct proportion to the financial cost.

When all the above data is considered, it is estimated that 3 out of 10 works performed in each project are rework and that half of the man-hours devoted to each construction site are wasted on repairs and dismantling (Skoyles and Skoyles, 1987). An important decrease in the volume of materials and time loss could be achieved by improving the management system and as a result, minimizing the ambiguities and change orders as well as clarification requests, to which they are due. Research estimates that what could be achieved is the reduction on total debris generated by rework activities by at least a 39.9% (CIRIA, 1995) to 50% (Lyra, 2010). By eliminating avoidable rework through the implementation of a coherent document and information management system, it would be possible to achieve a reduction ranging from 40% to 50% of wasted materials that are connected to rework and poor communication. Based on previous research, this particular type of waste ranges from 20% to 30% of the anticipated volume of debris (Hassan et al., 2020). In order not to be overoptimistic on forecasted possible benefits, the minimum value of estimated reduction in volume of wastage shall be used. Thus, calculations are based on the assumption that there will be the minimum anticipated 40% reduction over the minimum estimation that 20% of the total volume of waste generated per project is associated with poor document management.

Total expected waste savings for common project types are calculated over the total expected volume of construction waste using statistical waste benchmark data (BRE, 2012). Compiled by the Building Research Establishment (BRE) and presented in columns (C) and (D) in *Table 2*, this set of data has been adopted by the European Commission as the most reliable method for forecasting construction waste (EC, 2016). Column (E) demonstrates the m^3 of waste that are caused specifically by inadequate document management (20% of the values in Column (C) divided by 100 so that the figures are displayed per 1 m^2). The possible environmental benefits predicted per type of construction project are presented in column (F) and (G). Column (F) displays the reduction of waste volume in cubic meters per square meter of final constructed area (m^3/m^2) and column (G) per 100,000 of final cost (m^3/€100K).

The total environmental benefit can range from a reduction in volume of waste from 0.44 m^3/€100K for healthcare buildings to 0.79 m^3/€100K for residential projects. The number of skips that would have been used to transfer the debris can be used to visualize the quantity of materials that is eliminated from reaching landfills. A regular skip which is used in construction projects to accumulate debris has an average capacity of 6.125 m^3. The actual quantity of debris, however, that is transferred using each skip is half that amount, because usually 50% of the capacity is void (DEFRA, 2006). As a result, a skip of waste will have never been disposed of for every 3.0625 m^3 of debris saved. *Table 3* demonstrates the skip volume saved per project type. Data generated from column (F) are used in columns (I) and again in (H) divided by 100 so that the figures are also displayed per 1 m^2. Dividing the data in columns (H) and (I) by 3.0625 m^3 we can calculate the number of skips that would have been saved per project type in columns (J) and (K). Finally, the data in column (G) are treated in the same way to forecast the number of skips saved per €100,000 of project value in column (L).

The findings show that a minimum volume of approximately one-third in every skip bin would be saved for every 100 m^2 of an industrial building floor area to more than a half of every skip for every 100 m^2 of a public and commercial retail building's surface. If this is translated to monetary cost, a minimum of 14% for healthcare buildings to a maximum of 26% for residential projects of every skip would be saved for every 100,000 of the final building cost in euros. The exact financial benefit of these reductions cannot be easily estimated, as it depends on the exact type, price and mixture of wasted materials. In addition, savings in costs to purchase and store, to install and remove, as well as the cost of transfer and disposal (by reusing, recycling or landfilling) of materials that would have never been wasted should be considered. An important increase in the profit margin and more efficient construction techniques can be reached when adding these savings to the reduction in operational costs, which were previously discussed.

Efficient DMS can be achieved by employing free open-source DMS options or commercial software programs of affordable prices, in order to limit the cost of investing in a modern system. Even for small or medium-sized companies, this investment cost can be tailored to remain small and could actually prove unimportant

Table 2. *Total expected volume of construction waste (in ascending order) for common project types and the associated savings as per final constructed surface and building value*

Project type	(C) Total estimated m^3 of waste / 100 m^2	(D) Total estimated m^3 of waste / €100K value	(E) m^3 of waste related to poor document administration / m^2	(F) possible savings in m^3 of waste / 100 m^2	(G) possible savings in m^3 of waste / €100K value
Industrial buildings	13.0	8.71	0.0260	1.04	0.52
Leisure	14.4	7.42	0.0288	1.15	0.45
Commercial (other)	17.4	7.82	0.0348	1.39	0.47
Residential	18.1	9.92	0.0362	1.45	0.79
Healthcare	19.1	7.34	0.0382	1.53	0.44
Commercial (offices)	19.8	7.50	0.0396	1.58	0.45
Education	20.7	8.06	0.0414	1.66	0.48
Commercial (retail)	20.9	12.09	0.0418	1.67	0.73
Public buildings	20.9	8.63	0.0418	1.67	0.52

Table 3. *Expected savings in waste cost (in ascending order) by lessening the volume of debris that is removed on-site and transported for disposal in regular skips of waste*

Project type	(H) possible savings in m^3 of waste / m^2	(I) possible savings in m^3 of waste / 100 m^2	(J) skips of waste saved / m^2	(K) skips of waste saved / 100 m^2	(L) skips of waste saved / €100K value
Industrial buildings	0.0104	1.0400	0.00340	0.34	0.17
Leisure	0.0115	1.1520	0.00376	0.38	0.15
Commercial (other)	0.0139	1.3920	0.00455	0.45	0.15
Residential	0.0145	1.4480	0.00473	0.47	0.26
Healthcare	0.0153	1.5280	0.00499	0.50	0.14
Commercial (offices)	0.0158	1.5840	0.00517	0.52	0.15
Education	0.0166	1.6560	0.00541	0.54	0.16
Public buildings	0.0167	1.6720	0.00546	0.55	0.17
Commercial (retail)	0.0167	1.6720	0.00546	0.55	0.24

in relation to the expected benefits. Moreover, most companies already possess the required equipment on laptops and desktop computers to use and onsite use could be done even from up-to-date cell phones or larger portable devices already staffed, at no extra cost. Multiple benefits to adopting such a system are expected. However, the majority of construction teams still do not make use of them. Other benefits from revising the management system of construction documents should be quantified and assessed, for instance, savings by reductions in the project's printing and postal cost and impalpable benefits that might not be valued, but may still be important for the organization's objectives (Ward et al., 1991), like positive social repercussions, avoidance of severe costs related to future environmental regulations and improved marketing position.

Conclusions

Although the problem of waste has been well documented from very early on, construction waste in the EU is still estimated to be more than 35% of the total materials collected for disposal, confirming finds that the building industry is the champion in waste production. Statistics demonstrate that this amount has reached new heights with an increase of over 20%, from approximately 34 million tons in 2004 to over 41 million tons during the last 15 years (Eurostat, 2020).

This significant loss of valuable assets is not limited to the EU but it can also be confirmed on a global scale. An estimated 13% to 30% of all solid waste that ended up in landfills globally in 1996 was the outcome of CandD activities (Bossink and Brouwers, 1996). The breakdown of that amount shows that one-third can be attributed to new construction works versus two-thirds that originated from demolition works. In the United Kingdom (UK), the building industry was responsible for more than 70 million tons of debris annually (CIRIA, 1995) while over 60% of a total 222 million tons of debris in 2018 originated from construction, excavation and demolition works, an annual generation of over 137 million tons (DEFRA, 2021). Recent Statistics in the United States (USEPA, 2020) demonstrate that over 130 million tons of CandD debris were buried, with approximately half of all materials being forwarded to landfills. It is thus imperative from an environmental and social aspect to improve the performance of building projects and to promote effective material use of the construction sector as a whole. Research which demonstrates that one of the major sources of waste is poor information and document management cannot be neglected.

Thus, for construction projects to become more effective and leaner, their team members must possess a real-time project information system which could supply dashboard reports and recover associated essential documents (Fisk, 1988; Lee et al., 2005). Currently, building firms that employ a real-time document management system in construction projects are less than one out of ten (PlanGrid, 2018). There are potentially important economic and environmental gains by implementing an improved document and information administration system in construction projects. The total waste generated would be reduced through such a coherent system, suppressing costs of operations and construction.

The profit margins of building projects and the competitive advantage of construction firms as well as their environmental performance will increase through the improvement of information management. The investment in IT document management helps to extend the competitive capacity of construction organizations and as a result improves a fundamental factor in business (Carter et al., 1999). Construction firms which are unsuccessful in adopting modern systems that exhort data-driven operations may devolve in market standing and as a result might become redundant in the future (Snyder et al., 2018).

A reduction in wasted materials by one of the most polluting industry sectors in the world will contribute to counteracting against climate change, since fewer resources shall be spent on building activities. Sustainable development shall be promoted via a reduced supply chain energy footprint and the industry's social profile will improve, simultaneously preparing the sector for stricter future regulations regarding waste management.

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