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# THE POTENTIAL USE OF BIM TO AID CONSTRUCTION WASTE MINIMISATION

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Zhen Liu, Doctoral Student, [Z.Liu2@lboro.ac.uk](mailto:Z.Liu2@lboro.ac.uk)

Mohamed Osmani, Senior Lecturer, [m.osmani@lboro.ac.uk](mailto:m.osmani@lboro.ac.uk)

Peter Demian, Lecturer, [P.Demian@lboro.ac.uk](mailto:P.Demian@lboro.ac.uk)

Andrew N Baldwin, Director of IMCRC, [a.n.baldwin@lboro.ac.uk](mailto:a.n.baldwin@lboro.ac.uk)

*Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom*

## ABSTRACT

It is widely acknowledged that the construction industry has a major impact on the environment, both in terms of resource consumption and waste production. The construction industry is responsible for producing a whole variety of different onsite wastes; the amount and type of which depends on factors such as the stage of construction, type of construction work, direct or indirect stakeholders' design change contribution, and practices throughout the project lifecycle. A number of construction waste minimisation (CWM) techniques and tools are currently available to assist contractors to divert waste away from landfill. However, literature reveals that there are insufficient techniques and tools for reducing construction waste during the design and procurement stages. The last few years saw the emergence of Building Information Modelling (BIM) techniques, which can be adopted to improve sustainable construction performance. BIM is a maturing modelling philosophy, which has been applied to several building-related functions such as visualising designs, automating quantity takeoffs, checking compliance with regulations, and scheduling construction processes. Furthermore, BIM, as a real-time interactive and collaborative communication system, has the potential to help project stakeholders to collaboratively attain waste minimisation for sustainable construction and building throughout design, construction and throughout the lifecycle by improving building construction performance. Hence, this paper, which is part of an ongoing doctoral study, explores the potential application of BIM to design out waste. An in-depth literature review was conducted to provide a foundation for the doctoral study that aims to investigate the use of BIM as a potential platform for building design waste minimisation. The paper explores construction waste origins and causes, current waste reduction practices; examines current industry BIM practices and investigates BIM tools for sustainable project construction and management; and identifies the knowledge gaps in existing literature that pave the way for the subsequent data collection stages.

**Keywords:** Environmental impact, Sustainable construction, Construction waste minimisation (CWM), Building Information Modelling (BIM), Designing out waste.

## 1. INTRODUCTION

Sustainability is becoming a major catalyst for change in the built environment owing to its ever increasing energy consumption and material usage, which leads to waste and pollution. Waste generated from construction and demolition (C&D) activities in the UK accounts for 32% of total waste generation (WRAP 2011a). In addition, the last five years saw a striking increase in C&D waste in the UK. Indeed, In C&D activities generated 90 million tonnes of physical waste in 2005 (Zakar 2008); while recent figures from WRAP (2011a) revealed that this has increased to 120 million tones. Similarly, the current estimation of C&D waste disposed off to landfill is 40% (WRAP 2011a); whilst it was 30% in 2005 (Edgar 2007). The UK Waste Strategy for England 2007 identified the construction industry as a priority sector to move forward with the waste minimisation agenda (Defra 2007). Furthermore, the UK has set the ambitious target of zero construction waste to landfill by 2020 (WRAP 2011b). From a financial perspective, it has been estimated that the true cost of waste could as

much as 10 times that of disposal (WRAP 2011a). Thus, the construction industry is under an ever-increasing pressure to explore and develop effective and efficient techniques and tools to minimise its escalating waste production. A comprehensive literature review was conducted to explore the extent of the relationship between Building Information Modelling (BIM) and construction waste minimisation (CWM). The review examined construction waste origins and causes, current waste reduction practices; assessed current industry BIM practices, BIM tools for sustainable project construction and management; and discussed the knowledge gaps in existing literature that pave the way for the subsequent data collection stages of this ongoing research that will lead to the development of BIM aided CWM framework.

## **2. CONSTRUCTION WASTE MINIMISATION (CWM)**

CWM has been defined by the UK Environment Agency (1997) as reducing construction waste by preventive measures (prevention, reduction at source, and reuse of products) and waste management measures (quality improvement, and recycling). Similarly, Envirowise (1998) defined CWM as the process of systematic waste reduction at source, by preventing and reducing waste before its physical generation, and encouraging reuse, recycling and recovery. Therefore, CWM is a process which avoids, eliminates or reduces waste at its sources or permits reuse and recycling of the waste for benign purposes in construction (Riemer and Kristoffersen 1999).

### **2.1 CONSTRUCTION WASTE CAUSES AND ORIGINS**

By and large, construction waste origins are related to design changes, leftover material scraps, non-recyclable/re-useable packaging waste, design/detailing errors, and poor weather (Faniran and Caban 1998). Further, a study of attitudes of architects and contractors toward origins of construction waste indicates that construction waste is related to design, site operation, procurement routes, material handling and sub-contractor's practices (Osmani et al. 2006). Osmani et al. (2007) went further to compile and group the main sources of waste factors in terms of construction lifecycle stages, comprising contractual, design, procurement, transportation, on-site management and planning, material storage, material handling, site operation, residual, and other.

There is a consensus in literature that a significant portion of waste is caused by problems which occur in stages that precede production, and design stage is one of the major construction waste sources (Keys et al. 2000, Osmani 2011). That said literature failed to identify a clear linkage or relationship between consequences of amount of construction waste generated and their corresponding causes and origins. Additionally, Agopyan et al. (1998) argued that the lack of knowledge of waste generators is a noteworthy cause of waste. Furthermore, there are no forecasting comprehensive and reliable methods and tools to predict and estimate the amount of constructed waste before projects start on site (Formoso et al. 1999). Therefore, an accountable top-down dynamic relationship between main causes and origins of construction waste and their respective amount of construction waste generated. This was supported by Teo (2001) who acknowledged that there are limited construction waste reduction methods that specifically address known causes and origins of waste. On the other hand, the analysis of sources of waste indicated that a large quantity of material waste is due to flow activities, such as material delivery, inventories, and internal transportation and handling (Formoso et al. 2002). The transformational approach suggests that an independent control of each stage of production is required, whereas flow processes' approach suggests that a focus on the control of the total flow of production is needed (Koskela 1999).

There is a consensus in literature that all construction stages directly or indirectly contribute to onsite waste generation. However, the level and severity of waste production varied from stage to stages depending on a number of variables that include type of procurement, project brief, stakeholders' engagement and commitment, etc. That said, it is widely argued that waste reduction intervention should focus on pre-construction stages, particularly design, where 'virtual waste' (simulated waste generation during design stages), as opposed to 'actual waste' (physical onsite waste), could be effectively identified, evaluated and reduced.

## 2.2 CURRENT WASTE MINIMISATION PRACTICES

Numerous studies have been conducted through all stages of construction project lifecycle to examine and assess current CWM approaches, techniques and tools of CWM; these are summarized in Table 1, Table 2 and Table 3 respectively. The primary reference used for project protocol in terms of lifecycle stages is the Royal Institute of British Architects (RIBA) Plan of Work (RIBA 2011), which contains the following project stages: A) Appraisal; B) Design Brief; C) Concept; D) Design Development; E) Technical Design; F) Production Information; G) Tender Documentation; H) Tender Action; J) Mobilisation; K) Construction to Practical Completion; L) Post Practical Completion.

Table 1: Current CWM approaches in project lifecycle stages

Approaches	Preparation stages		Design stages			Pre-Construction stages			Construction and Use stages			Post-construction stages		Source
	A	B	C	D	E	F	G	H	J	K	L	M	N	
Designing out waste	★	★	★	★	★									Osmani et al. 2007, WRAP 2009
Procurement guidance							★			★				WRAP 2010
Material Logistic Plans									★	★			★	WRAP 2007a
Reverse logistics									★	★			★	Nunes et al. 2003
Supply chain management									★	★				Dainty and Brooke 2004
On-site sorting										★			★	Poon et al. 2001
Waste Management Mapping Model										★				Shen et al. 2004
On-site waste control										★				Formoso et al. 1999
Cost-effective waste management plan										★				Mills et al. 1999
On-site waste behaviour / attitude										★				Begum et al. 2009
Implementation of environmental management							★			★			★	Shen and Tam 2002

Table 2: Current CWM techniques in project lifecycle stages

Techniques	Preparation stages		Design stages			Pre-Construction stages			Construction and Use stages			Post-construction stages		Source
	A	B	C	D	E	F	G	H	J	K	L	M	N	
On-site recycling C&D wastes										★				CIRIA 2001
Materials flow analysis system							★			★				Bertram et al. 2002
Ready-mixed concrete waste management										★				Sealey and Jill 2001
Dynamic modelling of construction and demolition waste management processes										★				Hao 2008
Integrated GPS and GIS technology										★				Hi et al. 2005
Geographical Information System (GIS) and Life Cycle Assessment (LCA) mix for supply chain										★			★	Blengini and Garbarino 2010
Use of off-site technique: prefabricated / precast concrete elements				★						★				Baldwin et al. 2008
Modern methods of construction (MMC)				★						★				WRAP 2007b

- Current CWM approaches mainly focus on strategic vision forethoughts related to design, logistic and supply chain, and on-site waste issues.

- Current CWM techniques developed by the industry are mainly concerned with on-site, off-site, and logistic waste minimisation issues.
- Current CWM tools, such as SMARTWaste, are related waste audit and better onsite practices to comply with waste regulations, such as Site Waste Management Plans (SWMPs) (WRAP 2011d).

Table 3: Current CWM tools in project lifecycle stages

Tools	Preparation stages		Design stages			Pre-Construction stages			Construction and Use stages			Post-construction stages		Source
	A	B	C	D	E	F	G	H	J	K	L	M	N	
Waste forecasting tool (online tool)			★	★										WRAP 2011b
On-site waste auditing: SMARTWaste										★				McGrath 2001
Waste management planning (WMP)										★				McDonald and Smithers 1998
On-site waste control tools										★				Formoso et al. 1999
Site waste management plans (SWMPs)										★				WRAP 2011d
ConstructCLEAR (online tool)										★				BlueWise 2010
True cost of waste calculator (online tool)										★				BRE 2010
SMARTAudit										★				BRE 2008
BreMap (online GIS tool)										★			★	BRE 2009
SMARTStart										★			★	BRE 2007
Webfill (online tool)										★			★	Chen et al. 2006

The current CWM approaches, techniques and tools focus on separate project stages with overwhelming endeavours to manage waste onsite. However, limited effort is invested to concentrate on pre-construction waste generation related to supply chain management issues and procurement, design and tender stages. These offer substantial waste reduction opportunities on McKechnie's (2007) waste reduction opportunity curve. More recently, BRE (2011) called for the development of online CWM techniques and tools. Yet, there are no research studies on integrated e-waste minimisation or IT related approaches, techniques and tools across all life cycle stages of construction projects. These would particularly be suited to design out waste, since 33% of construction waste might be directly influenced by inappropriate design decision making and design changes (Innes 2004), which contribute to more than 50% of the total onsite waste production in construction projects (Faniran and Caban 1998).

### 3. BUILDING INFORMATION MODELLING (BIM)

BIM has evolved from computer-aid design (CAD) research. However, there is still no single, widely-accepted definition for BIM. BIM is defined in different terms from model and design data to construction management. From a three dimensional (3D) perspective, BIM is defined as a conceptual approach to building design and construction that encompasses 3D parametric modelling of building for design and detailing and computer-intelligible exchange of building information between design, construction and other disciplines (Sacks et al. 2010). From a design and project data management standpoint, BIM is a set of interacting policies, processes and technologies that generate a methodology to manage building design and project data in digital format across all life-cycle stages (Penttilä 2006). In terms of construction management, BIM is an intelligent simulation of architecture to achieve an integrated project delivery (Eastman et al. 2008). However, literature failed to define BIM in relation to sustainable construction performance. Therefore, BIM within the context of this research can be defined as a real-time interactive and collaborative communication system, having the potential to help project stakeholders to collaboratively attain construction waste minimisation throughout the whole lifecycle stages of a building by improving building construction performance.

### 3.1 BIM-RELATED SOFTWARE APPLICATIONS

A wide range of BIM software applications are currently available for various project performance purposes. As shown in Table 4, the vast majority of BIM related packages focused on design and pre-construction stages. There is a consensus in literature that BIM applications in their current use are vastly superior to 2D and 3D CAD-based tools, which do not maintain comprehensive integrity when changes are made. On the other hand, it is widely acknowledged that associating BIM with the development and use of 3D virtual building modeling techniques and technologies can yield very productive results.

Table 4: Current BIM applications in construction projects

Current BIM	Preparation stages		Design stages			Pre-Construction stages			Construction and Use stages			Post-construction stages		Source
	A	B	C	D	E	F	G	H	J	K	L	M	N	
Beck Technology DProfiler	√													Beck Technology
Carlson (CVE)	√													Olatunji and Sher 2010
Nemetschek Vectorworks	√		√	√	√	√	√							Nemetschek
Gehry Technologies Digital Project	√		√	√		√	√							Gehry Technologies
Navisworks JetStream v5 Roamer and Clash Detective			√	√										AGC 2006
Autodesk Green Building Studio					√									Autodesk
ArtrA										√		√		ArtrA
Autodesk Revit			√	√	√	√								Autodesk
Graphisoft ArchiCAD			√	√	√	√								Graphisoft
Bentley Systems Architecture			√	√	√	√								Bentley Systems
MasterBill, QSCAD Timberline					√	√	√							Olatunji and Sher 2010
Primavera, Construction Computer Software(CCS)					√	√	√							Olatunji and Sher 2010
PP Manager									√	√				Nemetschek
Navisworks TimeLiner						√			√					AGC 2006
Graphisoft Change Manager				√					√	√				AGC 2006
CostX, Inovayya, Tocoman, CRC estimator, Winest				√	√	√								Olatunji and Sher 2010
BIM and interoperability for precast									√	√				Sacks et al. 2010
Tekla Structures				√	√	√			√	√				Tekla
StructureWorks					√				√	√				StructureWorks
Design Data SDS/2					√				√	√				Design Data 2010

BIM applications in construction projects such as Beck Technology DProfiler and Carlson (CVE) are being used for economic assessments (cost estimating and income forecasting) of project substantive feasibility in the preparation stages. However, there is a lack of BIM tools to help satisfy the client's business requirement; identify potential solutions for feasibility studies; and outline project feasibility requirements.

Furthermore, BIM applications are predominantly used for decision making, and lean or sustainable building construction and performance analysis, such as energy and water analysis are used in pre-construction stages.

Although there are several BIM tools available for construction and post-occupancy stages, such as Tekla Structures (precast/prefabricate solution), StructureWorks (precast solution), Navisworks JetStream v5 (combining and reviewing 3D models), and PP Manager (linkage between CAD, factory and the ERP software); these are mainly used for prefabrication and construction management purposes in the construction stage.

Hence, the existing construction- related BIM applications are used contribute to:

- lower net information costs and risks;
- quick first response in early stage of design to make building safer;
- efficient monitoring lower operation cost;
- better views of facilities for better decision makings;
- reduced project cost and risks; and
- better building environmental performance

### 3.2 USE OF BIM IN MANAGING SUSTAINABLE CONSTRUCTION

There is an opportunity for BIM to offer valuable controlling features and analysis tools, to manage and maintain the original information of client needs through the design process (Penttilä 2007, Baldwin et al. 1998). BIM enhanced communication and collaboration is an important facet of managing successful sustainable construction (Grilo and Jardim-Goncalves 2010). It has been argued that BIM could enhance communication and collaboration; increase efficiency; and reduces errors, which in turn would reduce resources, energy, materials, and waste (Europe INNOVA 2008). Furthermore, BIM provides the opportunity of testing, revising, rejecting and accepting design ideas in real-time, such as the case for collaborative design methods.

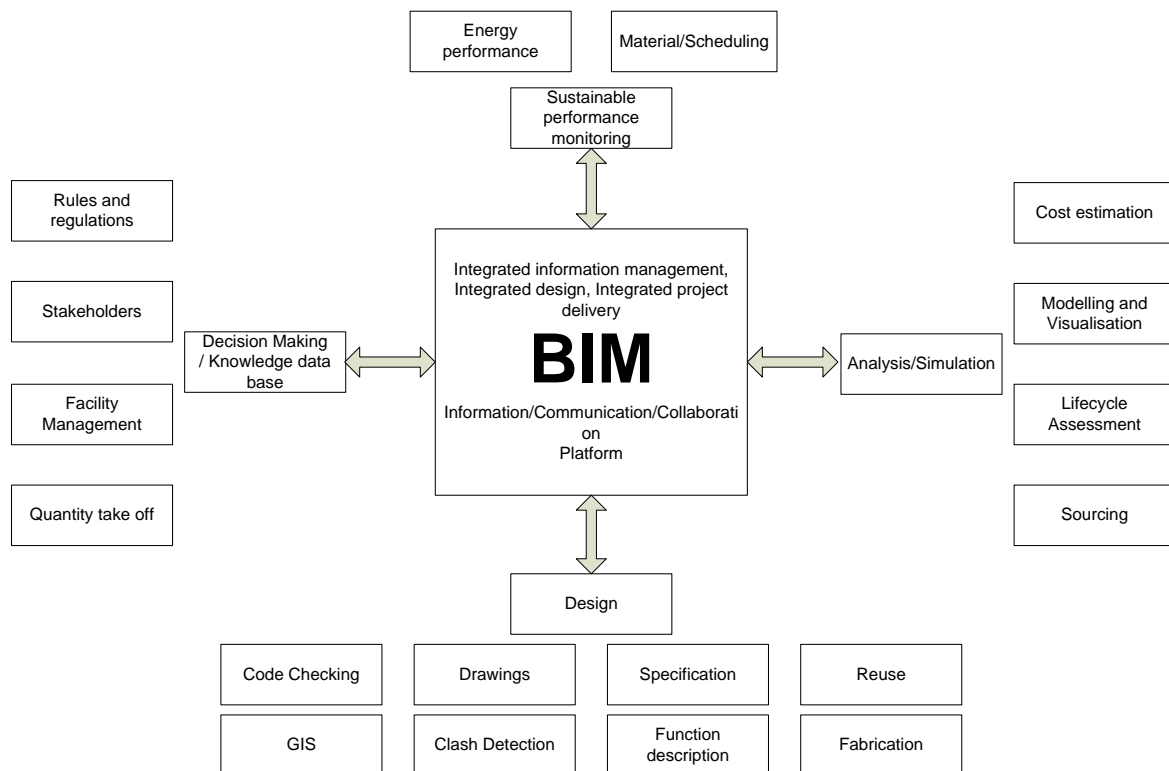


Figure 1: the IICC BIM platform for managing sustainable construction

The integrated information management associated with BIM for construction information would enable modelling, communication, collaboration and integration of sustainable design and construction requirements and actions across all project lifecycle. This would also improve decision making support and other project-related processes by optimising horizontal, vertical, and temporal integration of data and information management to enhance the value added for all project shareholders (Ilal 2007). Further, by adopting BIM technology, integrated project delivery (IPD) (AIA 2007) fosters a great degree of communication and promotes intense collaboration among the project team to enhance profitable, effective, and efficient project management (Hardin 2009). Therefore, integrated information management, integrated design, and IPD enhanced BIM solution can contribute to an efficient approach for managing sustainable construction.

BIM includes transactions at the data; information and knowledge semantic levels and falls within knowledge visualisation; a merger between information visualisation; and visual cognition and communication. (Eppler and Burkhard 2005). Knowledge, players and every component of project concerned will have the opportunity to contribute to managing sustainable construction as a whole; and influence others as individual by using BIM in the form of an integrated information, communication, and collaboration (IICC) platform. The IICC BIM platform for managing sustainable construction is shown as Figure 1. Design; decision making; sustainable performance monitoring; and analysis/simulation are four main application categories of IICC BIM platform for facilitating sustainable construction management.

Although, BIM offers promising methods for energy and resource efficiency, yet BIM methods at present do not consider a way forward for construction waste minimisation.

#### **4. KNOWLEDGE GAP ANALYSIS**

There are a number of techniques and tools for waste management that have been developed and introduced to the UK construction industry by leading organisations such as, BRE, WRAP, and CIRIA. These are widely adopted techniques and tools, such as a suite of software packages of SMARTWaste and SWMPs, which can facilitate onsite construction waste management. However, these techniques and tools focus on auditing and managing physical onsite construction waste that has already been generated, without measures to assist designers and other project stakeholders to design out waste. Online waste minimisation methods such as WRAP Waste Forecasting tools, and offsite techniques such as prefabricated/precast and modern methods of construction are being moderately used in construction projects. The extant of literature suggest that there are limited techniques and tools to assess and support construction waste minimisation performance for design decision making in Preparation, Design and Pre-Construction stages. On the other hand, BIM as a mature technique has been widely used in design and construction for many years. BIM applications, which have been supplied by established CAD software companies, concentrate predominantly on solving technical problems throughout all project stages.

Indeed, current BIM techniques and tools have been successfully used to enhance planning and construction relate issues during Preparation, Design and Pre-Construction stages; including improvement of sustainable project performance such as energy and resource efficiency. Although, it is widely accepted that BIM can help reduce waste-related costs and materials in construction projects (Nisbet and Dinesen 2010, Krygiel and Nies 2008, AIA 2007); at present there are no techniques and tools available that explore BIM as a platform to facilitate CWM. Hence this paper, which is part of an ongoing doctoral study, aims to develop a BIM aided CWM framework. The key objective is to improve sustainable construction waste minimisation by using BIM at the very early stages of design. The subsequent stages of this research will include simulating construction waste (virtual waste) through 3D building information (figure 2).

#### **5. CONCLUSIONS**

This paper has explored the potential to improve CWM through BIM systems in construction through a critical review of literature, by examining waste origins and causes, current waste reduction practice, and current BIM practices; and examining existing BIM applications that are currently applied to evaluate sustainable project construction and management. The most significant finding that stems from this paper is that although there was an emphasis on the need to explore the use of BIM for CWM; there are no previous attempts to adopt BIM as a vehicle to reduce construction waste. Hence, this research sets out to develop a BIM framework to aid CWM. The next stages of this research will involve designers, contractors and BIM experts to explore the most appropriate approach to adopt BIM as potential platform for CWM; select and customise a suitable BIM software; and develop and validate a BIM aided CWM in a live project.

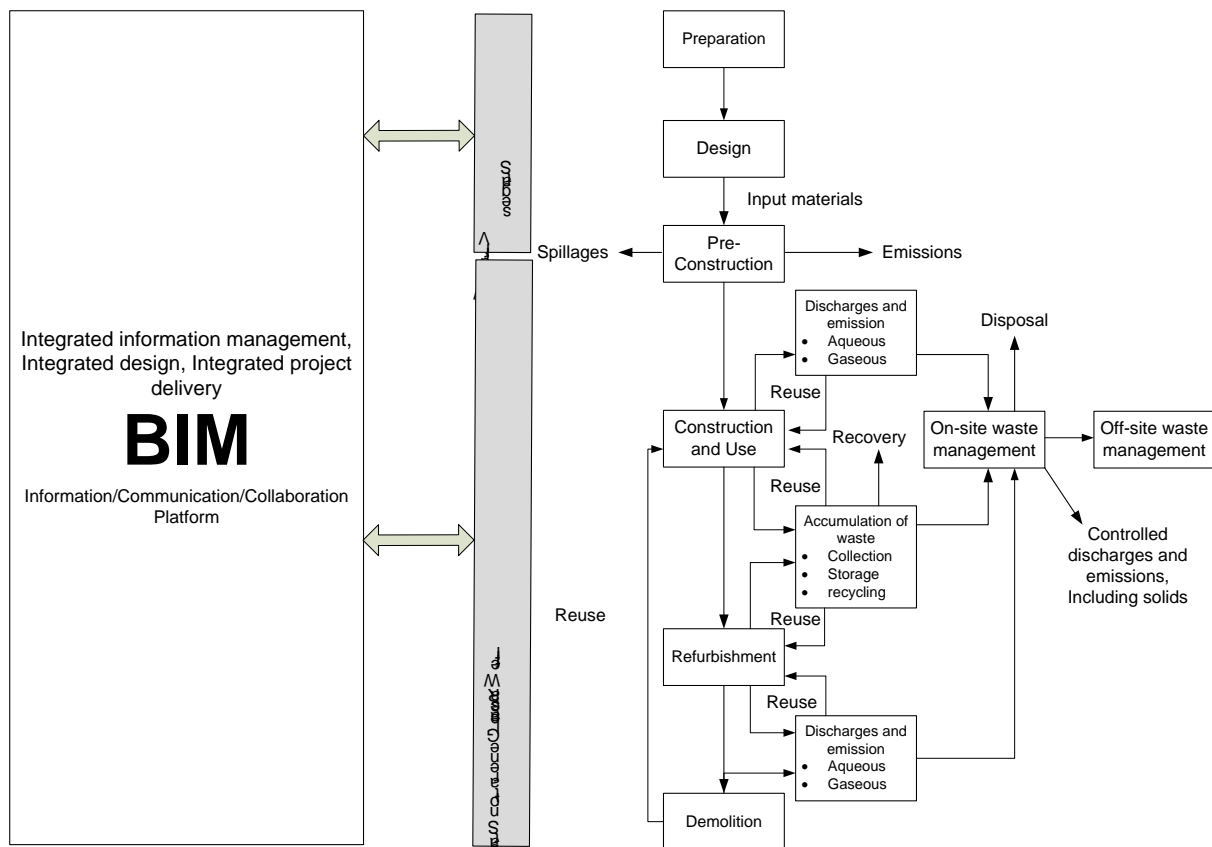


Figure 2: the ICC BIM platform and conceptual construction waste material input-output

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