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Sustainable Management of Construction Projects

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ABSTRACT

Sustainability in construction has become a core issue in the last years. Nowadays, it is considered as one of the key vehicles for the successful completion of construction projects. Nevertheless, common planning procedures for construction projects still lack sophisticated methodologies. Project management decision often focus on one particular project with well established goals, such as cost minimisation and time-line keeping while targets beyond time and cost are often not regarded properly.

The contribution highlights a sophisticated approach for construction project planning and reveals how this approach can be applied to modern construction management including aspects of sustainability. Thereby, planning is based on the assumption that projects usually do not occur as single events in reality but as part of a project portfolio.

Keywords: Sustainability, Construction Industry, Project Management, Optimisation, Scheduling

1. INTRODUCTION

Sustainability in construction has become a key factor for the successful completion of construction projects. In accordance to the raising attention from governments, non-governmental institutions, and the general public to environmental issues the construction industry faces the challenge to incorporate sustainable criteria when planning and executing projects (Ofori, 1992).

Research about sustainability in construction has up to now mainly focussed on design aspects and raw materials or materials used in buildings considering, e. g. their ability to efficiently use natural resources such as sun light and water, their potentials of avoiding harmful or hazardous emissions as well as their suitability for reuse, refurbishing or recycling. An analysis of the life cycle of buildings reveals that research efforts mainly concentrate on the first phase of the life cycle of a building. However, sustainable construction does not only refer to the design of the building, but also to the phases of construction, use, maintenance, and deconstruction. Thus, not only the design itself has to meet ecological requirements but also the following phases from construction up to deconstruction processes at the end of the life cycle. Hence, construction companies need to adapt their project management in order to follow sustainable principles.

In the next section the role of sustainability in the construction industry is discussed. Section 3 is devoted to waste management and material recovery options in the construction industry to establish closed-loop material flows. In section 4 an approach for sophisticated project management of construction projects is introduced and the concept of sustainability is applied to a mathematical planning model.

2. THE ROLE OF SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY

In a wider sense, the concept of sustainability can be described as the endeavour to ensure the achievement of economic growth without unreasonably exploiting the resource base, polluting the environment or upsetting any existing ecosystem. Therefore, entities like countries seek to decisions on the micro- as well as on the macro-level are in accordance with the objective of an environmentally friendly development. In detail this means, that the concept of sustainability involves the assessment of all the costs and benefits related to economic activities including externalities, for the efficient allocation of resources and an improvement in quality of life (Ofori, 1992).

The construction industry plays a key role putting the concept of sustainability into practice. Although essential for development, it can be described as major consumer of natural resources and potential polluter of the environment. Approximately 30–40 % of global energy consumption as well as 20–30 % of greenhouse gas emissions can be traced back to the construction industry.

Hence, impact of construction projects on the environment originates from the construction materials, the nature of the design of the houses, the construction methods, the location and layout, as well as from energy consumption for e. g. (Ofori, 1992):

- the production of materials, e. g. cement, steel, aluminium, plastics;
- the movement of equipment, materials, and components to and between sites;
- the operation of plant equipment on site, the running of the machinery in completed buildings, heating or cooling.

The negative effects of construction projects can be categorised as follows (Ramachandran, 1991):

- resource deterioration: depletion of forest resources by the use of timber; dereliction of land caused by quarrying; extraction of sand, clay and other deposits such as limestone; use of energy in the production and transportation of materials and in site construction activity;
- physical disruption of ecosystems and long-term climatic changes: diversion of natural waterways caused by dams, loss of flora and fauna, and upsetting of the ecological balance with possible health hazards; noise pollution caused by buildings in urban areas; affection of stability of fragile hillsides by highway construction;
- chemical pollution: particles released in the production and transportation of materials such as cement and quarry products; pollutants produced in the production of building materials; fibres released during working with asbestos products; accidental spillage of chemicals on site and careless disposal of waste.

From the preceding remarks it becomes obvious that the construction industry must actively react in a positive manner to environmental issues. Actions to be undertaken include (Ofori, 1992):

- arresting the depletion of resources, e. g. timber and clay, through economic use of resources as well as recovery of materials and the use of renewable varieties;
- preventing and arresting pollution by a proper waste management, the development and use of non-polluting materials, as well as by applying suitable techniques for construction, maintenance and demolition; low pollution or no-waste technologies;
- finding energy sources for the extraction of raw materials and the production of materials, the construction activity as well as for the use, maintenance and deconstruction of buildings.

Though, market conditions for the construction industry differ significantly in different regions (Schultmann and Sunke, 2006b) the awareness of taking sustainability as a serious issue in decision making processes becomes obvious.

Currently, activities to encounter these problems are limited to reactive behaviour, i.e. rather trying to respond to occurring damages than avoiding them. According to the proverb “prevention is better than cure”, a shift from reactive to proactive behaviour needs to take place, in order to prevent negative impacts of the construction industry. Hence, project planning procedures as one common in practice significantly need to be upgraded or innovated. A point of application is the introduction of waste management techniques into current project planning procedures to arrest the depletion of resources and prevent pollution in the production processes of new materials.

The next section especially focuses on the establishment of closed material flows in the construction industry and will reveal opportunities how to deal with waste and material accumulating at the end of the life-time of a building.

3. WASTE MANAGEMENT AND RECOVERY OF MATERIALS IN CONSTRUCTION

Following the purpose of sustainable construction as addressed before, a proper raw materials and waste management can positively contribute to the realisation of sustainable construction. Especially components and parts of buildings at their end of life time are a source for the realisation of benefits from resource preservation as well avoidance of greenhouse gas emission and waste (Guy and Shell, 2002).

Handling strategies for materials or components at the end of the life-cycle of a building are subject of product recovery management (PRM). PRM aims at recovering the maximum possible economic as well as ecological value of a product and its components. Therefore, its objective is to reduce the amount of waste accumulated at the end of a product's life cycle as well as to hold down the rate of the depletion of resources (Thierry *et al.*, 1995; Lambert and Gupta, 2005). The necessity for PRM might be imposed by governmental regulations or by customers, expecting companies to operate environment-friendly. The processing of used material can be differentiated into the direct reuse, product recovery management and waste management, depending on the degree of complexity and degree of deterioration. To ensure that materials circulate in so called closed material loops PRM provides direct reuse and product recovery strategies, as depicted in Figure 313.1, whereas material handled with options of waste management leave the material loop. Thereby, the closed material loop itself is a subsystem of an industry overlapping material flow.

In the closed-loop subsystem of component and material flows direct reuse (1) applies to modules which are redistributed into the product assembly and are site-installed or site-assembled again, e. g. wood or structural steel. Furthermore, direct reuse can occur for parts which are either redistributed into the product assembly (e. g. bricks) as a direct part of the building or into the modules assembly as a part of a module (e. g. windows, doors).

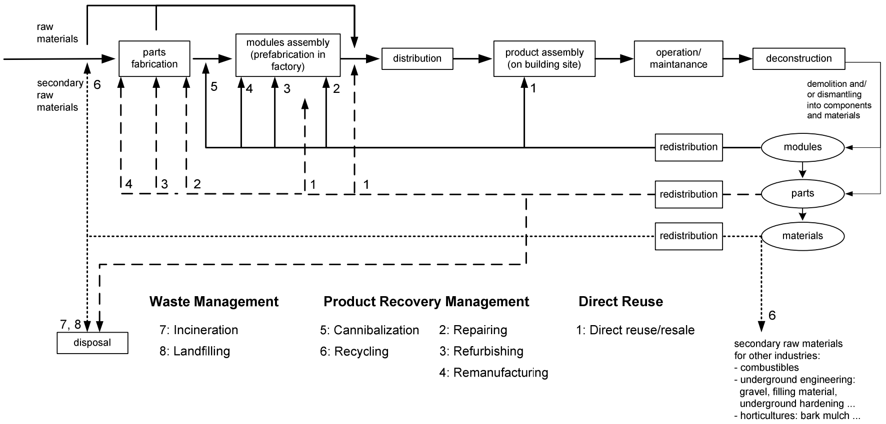

Figure 313.1 Construction material recovery options in closed loop material flows (Schultmann and Sunke, 2006a).

Repairing (2), refurbishing (3), and remanufacturing (4) occur on the modules level, when modules are redistributed to the modules assembly. In the modules assembly they are repaired, refurbished or remanufactured, e. g. boilers, valves, and windows. Analogous to the modules level, parts (e. g. metal and plastic piping, ductwork) can either be repaired (2), refurbished (3), or remanufactured (4) in the parts fabrication.

As parts are assumed to be the smallest possible unit of equipment of a house cannibalisation (5) can only be processed on the modules level and not on the parts level.

Recycling (6) can only be applied to materials, resp. can only be processed on the materials levels; i. e. modules have to be disassembled into parts and parts have to be dismantled into materials before recycling. The recycled materials can then be used as secondary raw materials in production and manufacturing processes of new parts afterwards. Additionally, interfaces exist to other industries, where the recycled material is not used in its original purpose, e. g. as secondary combustibles. Parts and materials (including often contaminated low mass products, e. g. paints, sealers or varnishes), which are neither recovered in the closed-loop system nor used in other industries, leave the material flow and are disposed either by incineration (7) or by landfill (8).

However, reuse and recovery strategies will merely be applicable to a building completely demolished or, if at all, only after a time consuming selection and separation of valuable components from rubble has taken place. Pursuing the objective to obtain modules, parts and materials in a high degree of diversification, selective deconstruction can raise the quality of materials under the focus of sustainability. This aspect of sustainability of a construction or a deconstruction project can thereby be represented by an environmental performance measure called reuse and recovery potential (RRP) (Schultmann and Sunke, 2006a). The RRP describes the ratio between the whole mass of a building and the mass of modules, parts, and materials which can be reused without pre-treatment as well as recovered with the strategies repair, refurbishing, remanufacturing, and recycling. In section 4.3 it is shown how the RRP can be integrated in a planning approach for sustainable construction.

4. SOPHISTICATED CONSTRUCTION PROJECT MANAGEMENT

4.1 COMMON PRACTICE IN PROJECT PLANNING

Project management in practice is concerned with conception, definition, planning, execution and termination of a project. This includes, for instance, the economic analysis for project selection, the specification of the project organisation, budgeting, as well as scheduling and resource allocation followed by control and quality management actions (Klein, 1999, p. 6). Especially the quality of scheduling and allocation of resources during project planning has a high impact on the outcome and fulfilment of the objectives of the project. Basically, these objectives have focussed on the competitive factors in the traditional building process which are time, cost, and quality on a micro planning level so far.

With the rising awareness of the necessity for the application of sustainable concepts in construction planning and extension of the micro environment of an enterprise to a more global context under the focus of sustainability, organisational decisions should reflect not just on economic constraints but also refer to social and environmental considerations, as can be seen in Figure 313.2.

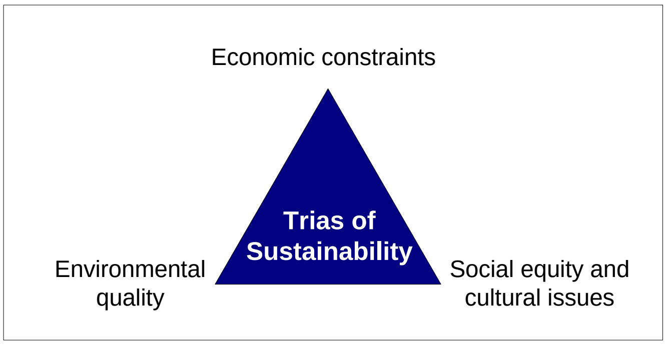

Figure 313.2 Factors of a sustainable development (Bourdeau, 1999).

Common project management in practice, especially in the construction industry, primarily focuses on the economic and is often conducted with simple techniques such as Gantt charts, the Critical Path Method (CPM) as well the Programme Evaluation and Review Technique (PERT) and network diagrams when activity durations and precedence relations are known and deterministic. These methods suffer two major shortcomings. At first they have in common that they lack a proper time and capacity planning by assuming unlimited availability of personnel and resources over the planning horizon, i. e. the analysis is based on the time requirements of the activities neglecting the resource demand. Hence, problems arise in most of the real-world projects when activities require resources that are only available in a limited amount. Secondly, they are not designed to integrate other aspects than time and cost and are therefore not suitable to be employed in the global context of construction project management addressing environmental as well as social aspects.

Generally, quantitative methods for project scheduling can compensate the lack of appropriate time and capacity planning in project planning approaches. Additionally, the flexibility of these models offers interfaces to integrate also environmental aspects (Schultmann, 2002b). For instance, such planning models can be utilised to organise projects including selected processes and equipment under resource constraints —for instance deconstruction projects— which aim at supplying a large number of modules and parts in a quality which facilitates a further recovery. However, these methods have not yet been paid much attention to in the construction industry. Hence, in the following a sophisticated quantitative planning approach for sustainable construction project scheduling considering economic as well as ecological aspects based on a generalised quantitative model known from Operations Research is developed.

4.2 PROJECT PLANNING AND OPTIMISATION

Project planning problems with the aim of allocating scarce resources to project activities considering limited resources and assigning start and finish dates to each activity under a defined project objective are called resource-constrained project scheduling problems (RCPSP). Basis for the RCPSP model is a representation of an activity-on-node network, as depicted in Figure 313.3 for the example of deconstruction.

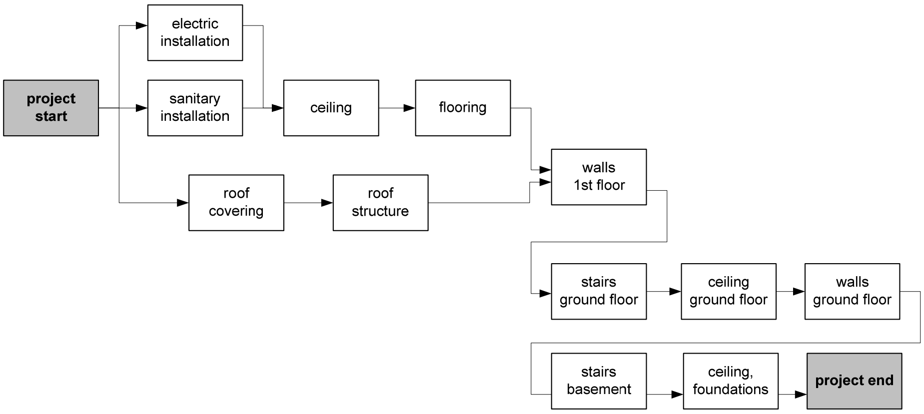

Figure 313.3 Activity-on-node network of a deconstruction project (simplified).

The nodes of such a network represent the construction, respectively deconstruction activities j (also known as jobs) of the project and the arcs represent the technological order of the activities, also referred to as precedence relations. Additionally, the network contains a unique source “project start” and a unique sink “project end”. For each activity a duration (e. g. 3 days) as well as a resource consumption (e. g. 1 worker, 1 excavator) is assigned, whereas the duration and the resource consumption of the source and sink activity are zero.

A project scheduling problem consists of two parts: an objective function that has to be optimised and constraints. Hence, a mixed-integer formulation for project planning of multiple projects with the decision variable x_{ijt} can be depicted as follows:

$$\text{MIN} \qquad \sum_{i=1}^{I} \sum_{t=EF_{iJ}}^{LF_{iJ}} \frac{t \cdot x_{iJt} - DD_i}{I} \tag{313.1}$$

subject to

$$\sum_{t=EF_{ij}}^{LF_{ij}} x_{ijt} = 1 \qquad i = 1,\dots,I\,;\; j = 1,\dots,J \tag{313.2}$$

$$\sum_{t=EF_{ih}}^{LF_{ih}} t \cdot x_{iht} \le \sum_{t=EF_{ij}}^{LF_{ij}} (t - d_{ij}) \cdot x_{ijt} \qquad i = 1,\dots,I\,;\; j = 1,\dots,J\,;\; h \in P_{ij} \tag{313.3}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} q_{ijr} \sum_{z=t}^{t+d_{ij}-1} x_{ijz} \le Q_r \qquad r = 1,\dots,R\,;\; t = 1,\dots,T \tag{313.4}$$

$$x_{ijt} \in \{0,1\} \qquad i = 1,\dots,I\,;\; j = 1,\dots,J\,;\; t = EF_{ij},\dots,LF_{ij} \tag{313.5}$$

with

i	project i of project portfolio, $i = 1,\dots,I$
j	job of project i, $j = 1,\dots,J$
d_{ij}	duration of job j of project i
EF_{ij}	earliest finishing time of job j of project i
LF_{ij}	latest finishing time of job j of project i
r	renewable resource type r, $r = 1,\dots,R$

q_{ijr} resource consumption of job j of the renewable resource type r in project i

Q_r resource availability of the renewable resource type r

P_{ij} set of immediate predecessors h of job j of project i

x_{ijt} decision variable

$$x_{ijt} \begin{cases} 1, & \text{if job } j \text{ of project } i \text{ ends in period } t \\ 0, & \text{else} \end{cases}$$

The objective function (313.1) minimises the mean project delay with DD_i representing the due date for each project i. Constraints (313.2) ensure that every job is processed once. Constraints (313.3) are precedence constraints of jobs. Constraints (313.4) limit (for each resource type) the resource demand of the jobs which are currently processed in order not to exceed the constant resource availability per period Q_r. Finally, constraints (313.5) define the decision variable as binary.

The model introduced allows an optimisation of economic driven objectives such as time and cost. In order to additionally consider sustainable criteria in production and construction processes triggered by environmental constraints or legal instruments, an approach for sophisticated construction project management is developed in the next section. This is done by integrating recovery options for different materials and components into planning procedures in the construction industry.

4.3 ADVANCED MODEL FOR RECOVERY MANAGEMENT IN CONSTRUCTION PROJECT SCHEDULING

Considering the waste management approach for construction material with its recovery options as addressed in section 3 and the optimisation model depicted in section 4.2, the likely highest potential of material recovery management is realised in deconstruction projects. However, the objectives of common project management models are usually time or monetary oriented (cf. objective function (313.1)). With the RRP introduced in section 3 it is possible to define and operationalise some sustainable objectives. For instance, the maximisation of the quota of recoverable components and materials of a building in a deconstruction project, e. g. claimed by legal instances. By doing so, each job j of project i has to be assigned an individual RRP ε_{ij} which is defined as follows:

$$\varepsilon_{ij} = \frac{\sum_{k \in K_r} a_{ijc}}{\sum_{k \in K} a_{ijc}} \tag{313.6}$$

with

ε_{ij} reuse and recovery potential of job j of project i

a_{ijc} mass of material c deconstructed by job j of project i

K_r number of materials for further reuse or recovery;

$K_r = \{ c \in K \,|\, c \text{ to be reused or recovered} \},\; K_r \subseteq K$

K number of all materials

Usually, an activity can be processed in several alternatives (for instance, the deconstruction of a wall can be performed either by using pneumatic hammers, a grabbing bucket or by demolishing it (Schultmann, 2002a)), which are modeled as mode m $(m = 1,...,M_j)$. Hence, the decision variable x_{ijt} hast to be altered into x_{ijmt} defining whether job j of project i in mode m ends in period t or not, whereas the source and sink activities can only be processed in one mode. Each alternative represents a deconstruction technique determining the resource consumption, the duration of the activity, and the mass of the material deconstructed in the defined mode m. Additionally, each alternative realises a different RRP ε_{ijm} in dependency on the mode processed (Schultmann, 2005).

With the RRP introduced the objective function (313.1) is replaced with:[1]

$$\text{MAX} \qquad \varepsilon = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \frac{\sum_{t=EF_{ij}}^{LF_{ij}} x_{ijmt} \sum_{k \in K_r} a_{ijmc}}{\sum_{k \in K} a_{ijc}} \tag{313.7}$$

While objective function (313.1) guarantees a time optimal solution by minimising the project finishing time, objective function (313.7) maximises the recovered amount of material in a deconstruction project by assigning finishing times to jobs in a selected mode ensuring that precedence

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[1] Note: also constraints (313.2) – (313.5) have to be amended to be applicable to the multi mode case. For an example see (Schultmann, 2001).

(equations (313.3)) and resource constraints (equations (313.4)) are not violated.

Solving optimisation models several solution procedures might be applied. Solution procedures for RCPSP and its extensions are divided into exact algorithms and heuristic approaches. Especially heuristic procedures concentrate on providing an efficient method to calculate an acceptably good solution within a reasonable computational time. Comprehensive reviews for the RCPSP can be found in (Brucker *et al*., 1999; Demeulemeester and Herroelen, 2002; Kolisch and Hartman, 2006).

However, simply maximising the RRP of the project without regarding time, resource and cost oriented objectives, such as the minimisation of resource idle times, the leveling of resource consumption and the maximisation of the net present value of a project or a project portfolio might result in economic unfavorable solutions. Hence, different objectives should be considered and, if possible, optimised simultaneously. However, simultaneous optimisation of objective functions (313.1) and (313.7) might cause problems because of possible conflicts between the objectives. These conflicts can be solved by applying approaches from multi objective decision making like goal programming or scoring models by assigning weights to different objectives from the objective dimensions of time, money, resources and environment.

5. CONCLUSIONS

The aim of the paper was to highlight a sophisticated approach for construction project planning and to reveal how this approach can be applied to modern construction management. Hereby, special attention was paid to the necessity to consider aspects of sustainability in construction management.

The approach introduced allows the management of multiple projects simultaneously, i. e. to manage a project portfolio, with optimisation methods and shows interfaces for the integration of further criteria besides resource constraints. These restrictions are especially interesting if waste management and greenhouse gas emission control are put into practice in construction projects.

The approach presented here, i. e. the integration of waste management and recovery strategies into the planning process of construction projects can be used to promote sustainable criteria into construction project management. Further research should address the integration of regulations of legal instances such as emission reductions imposed by the Kyoto Protocol or the Agenda 21. This will become a core issue in emerging markets countries, such as China and India, were the negative impact of numerous construction activities causing increasing pollution levels cannot justify the race to catch up with industrialised countries in perpetuity.

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