Life-Cycle of Structures and Infrastructure Systems – Biondini & Frangopol (Eds)

Can we reuse plasterboards?

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ABSTRACT: Gypsum turns plaster when it is dehydrated, and it returns to gypsum when it is hydrated. Because of this, gypsum is 100 % recyclable in theory. However, in reality, only 4% (in mass) of the plasterboard is from recycled plasterboard. This is because of the substances, other than fresh gypsum from quarries, to make plasterboard, and the current demolition methods that cause material contamination. The current practice of manufacturing, construction, and deconstruction of plasterboard necessitates significant resource extraction and carbon emissions, and the situation is unlikely to change in the foreseeable future. Reusing, instead of recycling, construction material is effective in reducing resource extraction and carbon emissions, however, it has not been investigated at all for plasterboard. Thus, this paper explores the potential and feasibility of reusing plasterboard used for exterior infill walls, which is made of plasterboards and an increasingly used façade construction method in the UK.

1 INTRODUCTION

Exterior lightweight infill walls (see Figure 1) are increasingly used in building façade construction in the UK (SCI, 2019a). These walls are often replaced during the refurbishment of buildings to adapt spaces to new functions or to comply with new energy efficiency or humidity control targets (Morgan & Stevenson, 2005). The replacement typically occurs every 30 years (ARUP, 2022), even though most of the components could maintain their good performance generally much longer than 30 years.

The authors of this article have recently evaluated the carbon emission from the exterior lightweight infill wall construction/deconstruction, using lifecycle assessment procedures (RICS, 2017) of an actual building (located in the Greater Manchester area, UK). The authors found that the construction and deconstruction of exterior lightweight infill walls could contribute significantly to the amount of carbon emission (more than 20% of embodied carbon emitted from the entire building). Thus, the authors have investigated the potential of disassembly of infill wall components for future reuse.

The earlier work by the authors investigated the potential for the disassembly and reuse of lightweight cold-formed steel (CFS) members within the infill wall (Kitayama and Iuorio, 2022). The steel frame members in infill walls are the major contributor to the carbon emission from the construction and deconstruction of infill walls. However, the exterior infill walls are made up of, not only steel frames, but several other components, including internal plasterboards, cavity insulation, external plasterboard, external insulation, and cladding. The contributions of carbon emissions from the construction and deconstruction of these components are significant. Also, the current practice of construction and deconstruction of any of these components has not established circular practice (i.e., reuse or energy-efficient recycling). Moreover, past research and practice focused on recycling to improve the efficient use of materials and carbon reduction, however, a significant improvement in material use and carbon reduction from recycling has not been achieved and will not be achieved in the foreseeable future.

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Reusing, instead of recycling, construction material can be effective in reducing resource extraction and carbon emissions, however, it has not been investigated at all for plasterboard, which is one of the main components of infill walls. Thus, this paper first examines the potential for the disassembly and reuse of gypsum plasterboard based on available publications, including journal articles, technical reports, Environmental Product Declarations (EDPs) and other company documents. The examination follows the order of lifecycle stages specified in BS EN 15978 (BSI, 2011), which are: product stage, construction process stage, use stage, and end-of-life stage. Subsequently, the feasibility of disassembly and reuse of plasterboard is discussed by looking at three different aspects: connections between plasterboard and steel profiles, available experimental data, and construction methods used for infill walls.

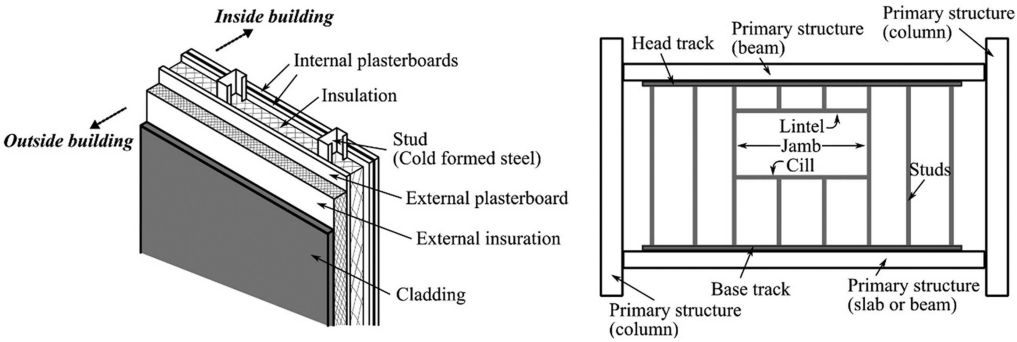

Figure 1. Exterior infill wall: (left) notations of infill wall components; (right) notations of lightweight cold-formed steel members and surrounding primary structure.

2 LIFECYCLE STAGES OF PLASTERBOARD

2.1 *Product stage*

According to Etex's EDP (Etex, 2018), the product of plasterboard consists of plasterboard (94.8%), paper liner (3.6%) and additives (1.6%). Among the 94.8% of the plasterboard, 36% is from mineral quarrying, 60% is from by-products from a coal-burning power station, and 4% is from recycled plasterboard (Etex, 2018). The rate of recycled gypsum in new plasterboards is limited to only 4%. This is due to the presence of impurities, introduced with the use of additives and the lining paper. There is an ongoing research program in the UK and abroad that aims to increase the recycled gypsum content in new plasterboards by increasing the purity rate of the collected gypsum waste (Erbs et al., 2018; Castro-Díaz et al., 2021). However, usually, the development and implementation of new technologies take a long time (Allwood et al., 2019).

2.2 *Construction process stage*

For the construction of exterior infill walls, the plasterboards are fixed to the studs of a lightweight steel frame, using self-drilling screws (Siniat, 2021). Screws are used at a minimum of 13mm from cut edges. The screws for the infill wall linings are used at a maximum distance of 300 mm (Siniat, 2021). The plasterboards should not be screwed to the head track, to avoid compromising the free movement relative to the structure (SCI, 2019a). One or two plasterboards are used for the internal linings for the infill walls depending on the designed performance for fire resistance, sound and heat insulations, and strength to wind load and cladding weight.

2.3 *Use stage*

The plasterboards do not need maintenance, repair, replacement, or refurbishment during the use stage. Plasterboards can be used in UK and European buildings for 50-60 years (Etex, 2018, 2021). While the expected life of the plasterboards is long (50-60 years), the infill walls, of which plasterboards are parts, are usually replaced every 30 years (ARUP, 2022) during the refurbishment of the building to adapt spaces to new functions or to comply with new energy efficiency or humidity control targets. The warranty period of plasterboard for some prefabricated types of infill walls is 30 years (Etex, 2020) but the warranty may be set to target the typical replacement period and it is not representative of the plasterboard's actual functional period. Indeed, warranties issued by manufacturers are often much shorter in their lifetime than the expected service life (Hartwell et al., 2021).

2.4 *End-of-life stage*

Most of the plasterboards (83% in mass) are landfilled or recycled and used for other purposes (e.g., agriculture), and the rest (17%) is sent for recycling to manufacture new plasterboard (Etex, 2018). Landfilling the plasterboard generates hydrogen sulphide, a toxic and foul-smelling gas, and incinerating the plasterboard results in the release of sulphur gas, a contributor to acid rain formation (Ndukwe & Yuan, 2016). In the UK, the method of landfilling plasterboard waste is getting stricter (DEFRA, 2010), and the landfill tax is increasing (DEFRA, 2013). Among the 83% of plasterboards that are either sent to landfilled or reused, the rate of landfilled plasterboard is declining due to the agreement with all stakeholders to reduce the waste sent to landfill (Jiménez-Rivero & García-Navarro, 2017). The low rate of recycling (17%) is due to the impurities of the collected plasterboard. The amount of recyclable post-consumer plasterboard may be increased when the plasterboard is dismantled and segregated from other wastes at the deconstruction site (Jiménez-Rivero, 2016).

In summary, the rate of recycled plasterboard in newly manufactured plasterboard is very low and the technology to increase it is still under development, the amount of landfilled plasterboard needs to be reduced due to the cost and detrimental environmental effect, and plasterboard used for infill walls can be used longer (50-60 years) than they are typically used for (30 years). The first two demonstrates the necessity of alternative way of improving resource efficiency and reducing carbon emissions from recycling and landfilling plasterboard. The third point demonstrates the potential of plasterboard being reused to extend the life of the plasterboard that is used in place. It is also clear that for the reuse of plasterboard to be practical and implemented in the near future, the technology must already exist or, at most, minor modifications of current technologies need to be conceived, as the development and implementation of totally new technologies take time (Allwood et al., 2019).

3 CAN WE REUSE PLASTERBOARD?

The reuse of plasterboard is beneficial as it can reduce the carbon emission from the production of the plasterboard. It also reduces the extraction of gypsum from quarries. Thus, we want to know if the plasterboards can be reused. In this section, the feasibility of reusing the plasterboard is discussed from three aspects: (i) Connections in plasterboard, (ii) Experiment of plasterboard, and (iii) prefabricated systems to respond to the question, "Can we reuse plasterboard?"

3.1 *Connections in plasterboard*

To disassemble and reuse plasterboards, the connections between the board and light steel frames need to be disconnected. As described in the previous section, the connections are made using screws between the plasterboard and studs, and between the plasterboard and base track. The connections need to have sufficient stiffness and strength to stabilise the infill wall. According to the company EDPs, the screws can be removed, and other screws can be used at the same location where the hole already exists, although some repair actions may be necessary. This is because when the screws are used in the pre-existing screw halls, the stability of the screw may be weak and needs to strengthen the connection. Specifically, the manufacturer of weather defence board (external plasterboard) recognises the situation when the screws are used at the pre-existing screw halls, “Multiple attempts to fix a screw may create holes, inspect for holes carefully and seal” (Siniat, 2021).

When it is not feasible to remove the screws between the plasterboard and steel frame members due to the difficulty in finding their locations (e.g., the screws are not visible because the wallpapers hide them), the plasterboard may be locally cut to find the connections. This is deemed possible as there is an established repair method of plasterboard for up to certain areas of damage. The manufacturer of plasterboard specified the following repair options for different levels of damage (Siniat, 2021):

- Small areas of damage, up to 15mm x 15mm and a maximum of 3mm deep, may be patched using Siniat Fire Rated Silicone Sealant or Siniat Weather Defence™ Joint Tape.
- Areas up to 300mm x 300mm and a maximum of 5mm deep, may be filled with Siniat Aquamix water-resistant compound.
- An area larger than 300mm x 300mm or if the board has been perforated by damage must be replaced. Additional metal noggins or straps may be required to support the board.

The EDP for the internal plasterboard from the same company also states that a certain amount of damage is repairable (Etex, 2019): “Mechanical damage can be repaired using jointing compound, due to the easy repair associated with the plasterboards and without any adverse effects on function. Plasterboards can be easily replaced with new boards in the event of more extensive damage.”

Other methods may be introduced to ease the separation of plasterboard from the steel frames, for example, by developing a connection between the plasterboard and steel frame using a hooking or hanging mechanism, developing easily detachable adhesives, or using dot snap fasteners, Velcro strips, or magnetic strips. These connections need to be satisfactory to the essential structural functions of the infill walls, i.e., support the weight of the cladding and resist the shear and pull-out force induced by wind load. However, developing and implementing such new ideas in the practice may take time.

3.2 *Experiment of plasterboard*

The material properties of various types of plasterboards and the strength, stiffness and ductility of connections between plasterboard and lightweight cold-formed steel members have been investigated by many researchers (Iuorio 2009, 2017; Chen et al., 2016; Petrone et al., 2016; Ye et al., 2016; Selvaraj & Madhavan, 2019a; Abeysiriwardena et al., 2021; Kyprianou et al., 2021; Stergiopoulos et al., 2022). The lightweight wall systems (plasterboard attached to either stud-only or studs and tracks) were also experimentally investigated by many (Bewick, 2013; Vieira et al., 2013; Liu et al., 2014; Peterman et al., 2014; Petrone et al., 2016; Landolfo et al., 2019; Selvaraj & Madhavan, 2018, 2019b; Kyprianou et al., 2021; Peiris & Mahendran, 2022).

The experimental results provide the material properties of the plasterboard and the strength of the walls (plasterboard + lightweight steel frame members). The information about the elastic range indicates that the wall systems or wall components are undamaged, therefore if carefully disassembled, they could be in a suitable condition for reuse. Recent research on structural members, other than exterior walls, at the connections of beam-to-slab, beam-to-column, and column-to-column, used the experimental results, in terms of the relationship between the deformation and strength, to discuss the feasibility of reusing the connected members (Uy et al, 2017.). These studies set 40% of the ultimate (peak) strength as the limit of reusability of the structural members. The 40% of the ultimate (peak) strength corresponds to the elastic deformation of the structural systems being deformed or stressed without damage. This type of experimental investigation, or re-evaluation of existing experimental results, provides further guidance on the feasibility of reusing the infill wall systems or plasterboards. A guideline document may be developed based on these test results to facilitate the reuse of plasterboard and wall systems. For other popular structural members, such as structural steel, for example, a guideline for assessment, testing and design of reclaimed members exists (SCI, 2019b). According to this, straightness, loss of section, signs of damage, signs of fire exposure, plastic strain, etc. are checked for reuse of structural steel members. Similarly, a guideline document could be developed for the assessment of plasterboard panels for the determination of re-usability.

3.3 *Prefabricated systems*

Infill walls are often site assembled from lightweight cold-formed steel members that are delivered cut-to-length, followed by installation of plasterboard and other components (see Figure 1), or can be prefabricated as storey-high units (SCI, 2012). The disassembly of prefabricated, modules, in general, provides great opportunities for the refurbishment and reuse of modules or the recycling of materials and components used in the modules (SCI, 2001). Figure 2 shows the photos of prefabricated infill walls (SCI, 2008). Figure 3 presents the prefabricated panelised infill walls that were used in the construction of a school building in the Greater Manchester area, UK.

There are several advantages of using the prefabricated, panelised infill walls over other ways of constructing infill walls, such as (a) enhanced safety of installation workers (installation from inside the structure, reducing working externally at height), (b) reduced costs (reduced mast climber and scaffolding requirements; the crane is not necessary), and (c) reduced site waste.

Figure 2. Installation of lightweight infill wall in a primary structural frame (images from SCI, 2008), (left): Prefabricated infill wall with cladding, windows, and light steel frame, and (right) prefabricated infill wall with exterior plasterboard, windows, and light steel frame.

Figure 3. Prefabricated panelised infill wall with exterior plasterboard (photos taken by the authors on December 2021 in the Greater Manchester area, UK).

3.4 *Can we reuse plasterboard?*

Based on the discussions in this section, the authors consider that the plasterboards can be reused, and this can be done today. The reuse of plasterboard is done at the usual refurbishment time that takes place after 30 years of building construction. Currently, the plasterboard is reported to be functional for about 50-60 years, so the plasterboards can be reused once. Primarily, there are two ways of reusing the plasterboard: (a) removing plasterboard from steel frames and using it to construct another infill wall (or any other systems, i.e., internal partition walls, ceilings, etc.), and (b) keeping them attached to the steel frames and reusing the infill walls as prefabricated walls (see Figures 2 and 3). For (b), the plasterboards do not need to be separated from the steel frames. As discussed in the previous sections, any damage caused by the removal of plasterboard or prefabricated infill walls, or transportation processes, can be repaired by the existing technologies by manufacturers. In case the prefabricated infill walls are reused in other buildings, the size (width and height) of primary frames (steel or reinforced concrete frames) may be different from that of the original one. This is not a problem because the height and width of the infill walls are adjustable (i.e., the connection between studs and head track are adjustable; there are some spaces between the stud and column of the primary frame that are filled by insulation). Due to the advantages discussed in Section 3.3, prefabricated panelised infill walls may be most feasible for reusing plasterboard.

4 CONCLUSIONS

This paper first discussed the potential of reusing plasterboard. It showed that currently the rate of recycled plasterboard in the newly manufactured plasterboard is very low, the amount of landfilled plasterboard needs to be reduced, and plasterboard used for infill walls can be used longer than they are typically used. It then discussed the feasibility of reusing the plasterboard, looking at the feasibility of disassembling current connection systems, available experimental data, and prefabricated systems. Based on the developed analysis, the authors conclude that plasterboards have a high potential and feasibility to be reused, and the reuse of plasterboards can be done using existing technologies. Additionally, the authors consider that the prefabricated panelised infill walls are most suitable for the reuse of plasterboard due to their size and construction method. In the future experimental tests will be developed to provide further evidence of feasibility.

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