Politecnico di Torino

MSc Architecture for Heritage
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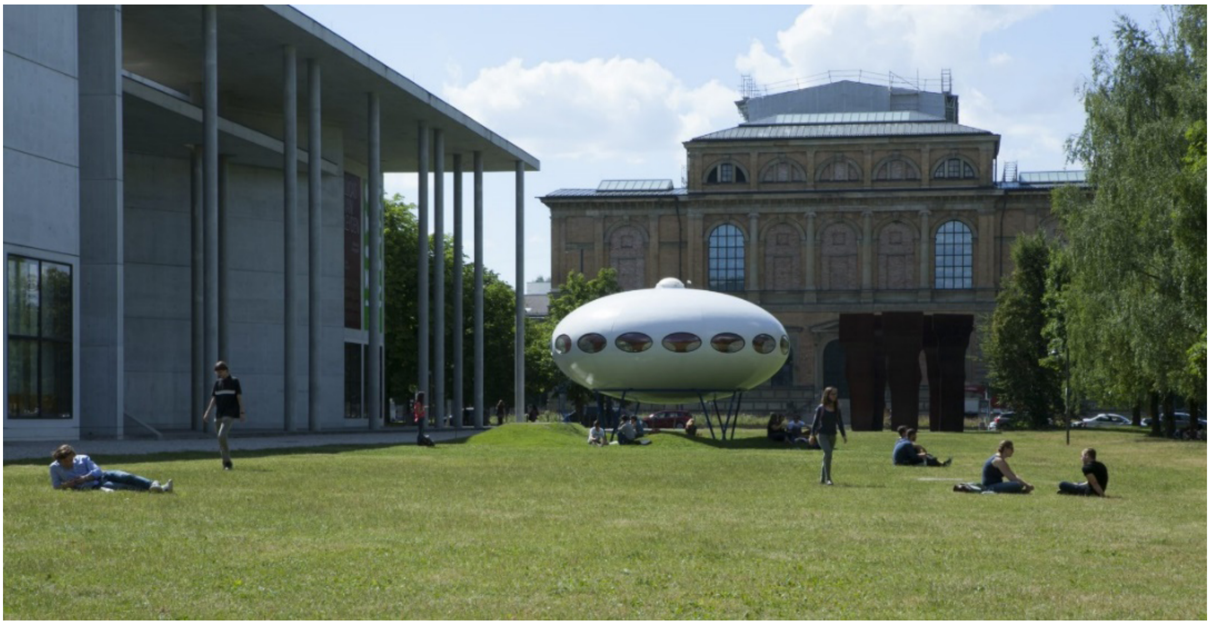

Restoration of sandwich panels in architectural heritage

Supervisor **Prof. Manuela Mattone**

Candidate **Maarten Trietsch**

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Cover image Futuro in Munich. Photo A. Laurenzo, Die Neue Sammlung.

Abstract

Sandwich panels are a building system that consists of an outer skin, a core and an inner skin. Architects have used sandwich panels to create a high-tech or industrial appearance, for example in the Sainsbury Centre for Visual Arts (1978, Norwich) by Norman Foster. Restoration of this construction system is important for safeguarding these buildings.

The sandwich panel was developed by Jean Prouvé around the Second World War. The panels have been produced on a commercial scale since the 1960s. Initially, sandwich panels were produced using steel skins, but later also materials like aluminium, glass-reinforced polyester, PVC, asbestos and precast concrete were used. The thin skins and critical detailing make sandwich panels vulnerable to decay.

Buildings from the 1960s to the 1980s are now reaching the end of their technical lifespan. Research on the restoration of the construction systems that built them is necessary for preserving them for future generations.

Sandwich panels are threatened by various types of decay, depending on the material, the context and the detailing of the panels. Conservation interventions are often possible, but some decay is irreversible. The preservation strategies for the various materials are discussed and evaluated.

Additionally, the restorations of four buildings employing sandwich panels are discussed in more detail. Although all use sandwich panels in their façades, the interventions vary significantly. In the projects analysed, the design of the restorations varies in level of conservativeness. The interventions performed reflect the extent of the decay, the proposed function of a building and the legal protections surrounding the work.

A deep understanding of the history, a thorough study of the material and a critical analysis of several case studies will illuminate the significance of sandwich panels in architectural heritage and guide the technical approach for the restoration of this remarkable construction system.

Riassunto[1]

Il panello sandwich è un sistema costruttivo che consiste di una lamiera esterna, un nucleo e una lamiera interna. Diversi architetti hanno usato i panelli sandwich per creare un'immagine high-tech oppure industriale, come il Sainsbury Centre for Visual Arts (1978, Norwich) di Norman Foster. Il restauro di questo sistema costruttivo è cruciale per preservare questi edifici.

Il panello sandwich è stato sviluppato da Jean Prouvé durante la Seconda Guerra Mondiale. Dopo gli anni 1960, i pannelli sono stati prodotti su scala commerciale. Inizialmente, erano prodotti usando lamiere in acciaio; in seguito sono stati introdotti materiali come alluminio, poliestere vetro-inforzato, PVC, amianto e calcestruzzo prefabbricato. I sottili rivestimenti e i dettagli critici rendono tuttavia il panello sandwich vulnerabile al deterioramento.

Gli edifici costruiti tra gli anni '60 e '80 stanno ormai al termine della vita tecnica. La ricerca sul restauro dei sistemi costruttivi con cui sono stati prodotti è dunque necessaria per preservarli per le generazioni future.

I panelli sandwich sono minacciati da varie tipologie di degrado, le quali dipendono dal materiale, l'ambiente e i dettagli costruttivi dei panelli. Gli interventi per conservarli sono spesso possibili, ma alcune forme di degrado sono irreversibili. In questa ricerca sono discusse e valutate diverse strategie di prevenzione dei materiali.

In aggiunta, vengono analizzati dettagliatamente gli interventi di restauro di quattro edifici con panelli sandwich. Nonostante tutti li utilizzino per la facciata, gli interventi risultano molto diversi tra loro. Nei progetti analizzati, i restauri variano a seconda del livello di conservatività. Gli interventi eseguiti, infatti, riflettono l'entità del degrado, la funzione prevista per l'edificio e le tutele legali relative alle opere.

La comprensione approfondita della storia, lo studio dettagliato del materiale e l'analisi critica dei casi studio metteranno in evidenza l'importanza dei panelli sandwich all'interno del patrimonio architettonico e guideranno l'approccio tecnico per il restauro di questo straordinario sistema costruttivo.

1 Si ringrazia Renata Rinaldi per la correzione della traduzione

Samenvatting

Sandwichpanelen zijn een bouwsysteem dat bestaat uit een buitenste huid, een kern en een binnenste huid. Architecten hebben sandwichpanelen gebuikt om een hightech of industriële uitstraling te creëren, bijvoorbeeld in het Sainsbury Centre for Visual Arts (1978, Norwich) van Norman Foster. Restauratie van dit bouwsysteem is belangrijk voor het behoud van deze gebouwen.

Het sandwichpaneel werd ontwikkeld door Jean Prouvé rond de Tweede Wereldoorlog. De panelen zijn geproduceerd op een commerciële schaal sinds de jaren 60. Oorspronkelijk werden sandwichpanelen gemaakt met een stalen huid, maar later werden ook materialen als aluminium, glasvezelversterkt polyester, PVC, asbest en prefabbeton gebruikt. De dunne huiden en de kritieke detaillering maken sandwichpanelen kwetsbaar voor verval.

Gebouwen uit de jaren 60 tot 80 bereiken op dit moment het einde van hun technische levensduur. Onderzoek naar de restauratie van de constructiesystemen die deze gebouwen hebben gevormd, is noodzakelijk voor het behoud ervan voor toekomstige generaties.

Sandwichpanelen hebben te maken met verschillende soorten verval, afhankelijk van het materiaal, de context en de detaillering van de panelen. Conservatie-ingrepen zijn vaak mogelijk, maar soms is verval onomkeerbaar. De behoudsstrategieën van de verschillende materialen worden besproken en geëvalueerd.

Daarnaast worden de restauraties van vier gebouwen met sandwichpanelen in meer detail behandeld. Hoewel deze vier gebouwen allen sandwichpanelen gebruiken in de gevels, lopen de interventies sterk uiteen. In de geanalyseerde projecten zijn er verschillen in hoe conservatief een restauratie is uitgevoerd. De interventies reflecteren de staat van het gebouw, de beoogde functie ervan en de wettelijke bescherming van het erfgoed.

Een diepgaand begrip van de geschiedenis, een grondige materiaalstudie en een kritische analyse van verschillende case studies illustreren de betekenis van sandwichpanelen in het gebouwde erfgoed en geven richting aan de technische benadering van de restauratie van dit opmerkelijke bouwsysteem.

Introduction

Deciding what is worth preserving is a delicate process. Often, the debate on architecture form more recent era was simplified and reduced to the a discussion about beauty and ugliness[1]. The focus was in many cases on the question "*should* we preserve?" instead of "*how* should we preserve?"[2] This question is particularly poignant in the case of buildings from the second half of the Twentieth Century. Constructions from this era were often built in materials and construction systems that are relatively fragile[3]. Changing energy requirements, functions and ideas on aesthetics form important threats to buildings that are often not (yet) protected by law[4].

The process of patrimonialisation requires a certain distance from the era which it regards, although the distance in time is significantly shorter than it was in the past[5]. After the start of the heritagisation process of the reconstruction period, some scholars have shifted the topics of academic research to later eras, like the *boom economico*, *trentes glorieuses* or *das Wirtschaftswunder*. In the Netherlands, the national government started enlisting buildings from after the reconstruction

1 Theodore Prudon, 'Preservation, Design and Modern Architecture: The Challenges Ahead', *Journal of Architectural Conservation* 23, nos 1–2 (2017): 28, https://doi.org/10.1080/13556207.2017.1327193.

2 Giulia Marino, 'Monuments modernes. matière, texture, image', *Tracés: bulletin technique de la Suisse romande* 142, nos 5–6 (2016): 6, https://doi.org/10.5169/SEALS-630481. Translation and italics MT.

3 Antonello Alici, 'Eredità e Attualità Del Secondo Novecento. Architetti e Architetture', in *Il Diritto Alla Tutela : Architettura d'autore Del Secondo Novecento*, by Gentucca Canella et al., Architetti Italiani Del Novecento (Angeli, 2019), 10; Paul J. Armstrong and Paul H. Kapp, 'Preserving the Past or Past Preserving: Sustaining the Legacy of Postmodern Museum Architecture', *Built Heritage* 6, no. 1 (2022): 4, https://doi.org/10.1186/s43238-022-00055-z; Jean-Marc Tulliani et al., 'L'innovazione Tecnologica Dei Materiali al Servizio Del Progetto: Focus Sull'Architettura Italiana Del Secondo Novecento', in *Il Diritto Alla Tutela: Architettura d'autore Del Secondo Novecento*, ed. Gentucca Canella et al. (Angeli, 2019), 396.

4 Bernard Colenbrander, 'Beperkte Kansen Op Een Zorgeloze Oude Dag: Het Lot van Gebouwen van Na 1965', *Bulletin KNOB*, 9 December 2023, 76, https://doi.org/10.48003/knob.122.2023.4.809; Marylise Parein et al., 'Waardebepaling van Jong Erfgoed (1970-2000): Het Belang van Materialiteit in Een Geïntegreerde Benadering', *Bulletin KNOB*, 9 December 2023, 86, https://doi.org/10.48003/knob.122.2023.4.811.

5 Parein et al., 'Waardebepaling van Jong Erfgoed', 85.

period (1945-1965) as national monuments[6]. This era is indicated in the Netherlands as Post65 and spans over the years 1965-1990[7]. In Italy, the ministry of culture initiated the project "Censimento delle Architetture Italiane dal 1945 ad oggi" which forms an inventory of important works of architecture after the Second World War[8]. This project uses a less strict periodisation than the Dutch one, as it spans 80 years. In France, national monuments are appointed in campaigns. The first campaign that was aimed at the twentieth century started in 1998, and most of them are organised on a regional level, like for instance the region Provence-Alpes-Côte d'Azur did in 2000 and 2006-2007[9].

In 2011, ICOMOS published the Madrid – New Delhi Document, in which the organisation took the stance that for the restoration of modern heritage, consolidation and conservation of important parts are preferred above replacement[10]. An impactful statement, because it has been proven to be quite challenging to replace building components from buildings belonging to the Modern Movement. Products are not available anymore and not all materials have been as durable as stone and brick. Advancements within building technology form another challenge. Technologies are radically different from what they used to be and because of serial production, the failure of one piece of the building, rises suspicion on the integrity of the other components[11].

A last difficulty when restoring buildings from a more recent era is the fact that many buildings were not built to last. This is applicable to structures that are considered part of the Modern Movement, like Sanatorium Zonnestraal (Hilversum, the Netherlands, 1928, by Jan Duiker, fig. 1). This building was built for the tuberculosis patients of the Diamond Workers Union of Amsterdam and therefore executed with a limited

6 G. Üslu, "Beleidsreactie op beleidsdoorlichting Erfgoed", Kamerstukken II 2022-23, 31511 nr. 51, 12 June 2023, https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2023Z10677&did=2023D25630.

7 Parein et al., 'Waardebepaling van Jong Erfgoed', 96; Lidwine Spoormans, 'Everyday Heritage: Identifying Attributes of 1965-1985 Residential Neighbourhoods by Involved Stakeholders', *A+BE | Architecture and the Built Environment*, no. 21 (November 2023): 36, 21, https://doi.org/10.7480/abe.2023.21.7283; Hugo Van Velzen et al., *Handreiking Borging van Post 65 Erfgoed* (Rijksdienst voor het Cultureel Erfgoed, 2022), 11.

8 Ministero della cultura - Direzione generale Creatività contemporanea, 'Censimento Delle Architetture Italiane Dal 1945 a Oggi', Censimento Delle Architetture Italiane Dal 1945 a Oggi, accessed 29 October 2025, https://censimentoarchitetturecontemporanee.cultura.gov.it/.

9 Sylvie Denante, 'Le Label Patrimoine Du XXe Siècle En France, l'exemple de La Région Provence-Alpes-Côte d'Azur: Présentation Des Résultats et de Outils de Diffusion', in *Architettura Minore Del XX Secolo : Strategie Di Tutela e Intervento*, by Francesca Albani and Carolina Di Biase (Maggioli, 2013), 176–77.

10 Marino, 'Monuments modernes', 8.

11 Prudon, 'Preservation, Design and Modern Architecture', 33.

fig. 1. The Main Building of Sanatorium Zonnestraal shortly after completion in 1928. Photo International Institute for Social History.

budget. The building was designed with materials that have a lifespan of 30 years, convinced that tuberculosis would be exterminated by that time, which would indeed be the time the building functioned as a tubercolosis hospital[12].

Also buildings from later times are often designed to be obsolete[12]. These structures were not built to last and often architects outlive their buildings. In the second half of the Twentieth Century, buildings are generally speaking designed using a life-cycle assessment, which already considers the destruction of a building after its financial service life[13]. It represents a chance of paradigm: instead of constructing for eternity, buildings are designed to last a (very limited) span of time. This phenomenon is characterised as 'ephemeral architecture'. Stemming from the ancient Greek word *ephemeros*, meaning 'short-lasting' or 'lasting-for-a-day', the adjective refers to architecture that is deliberately designed for a short(er) time, that could be thirty years, but also thirty days[14].

Perhaps one of the construction systems that suits the concept of

12 Isabelle Chesneau, 'Obsolescence et Modernité Architecturales', in *La Réception de l'architecture Du Mouvement Moderne: Image, Usage, Héritage:*, ed. Jean-Yves Andrieux and Fabienne Chevallier, Publications de l'Université de Saint-Étienne (Univ. de Saint-Étienne, 2005), 140.

13 Armstrong and Kapp, 'Preserving the Past or Past Preserving', 2.

14 Léa Catherine Szacka, 'Insight: Life, Death, and Ephemerality of Postmodern Architecture', *Arq: Architectural Research Quarterly* 22, no. 3 (2018): 271, https://doi.org/10.1017/S1359135518000659.

ephemerality the most, is the sandwich panel. A sandwich panel is a building element, that is composed of (at least) a core, usually made of a well-insulating material, and two external skins. Technological advancements and changing norms (for instance the construction ban of asbestos in the late twentieth century and beginning of the twenty first century[15]), ensured that the sandwich panel is a relatively temporary building element. Although the materials employed for the external side, like aluminium, steel or cement, can be quite durable, it is often the connection between outer skin and the insulation that causes problems (fig. 2)[16]. Buildings in sandwich panels are not always appreciated and are often demolished because restoration would be complex, not economically feasible, or not desired by politics, the owner or the general public[17].

Sandwich panels are a relatively new invention that rose to great popularity over the course of the past

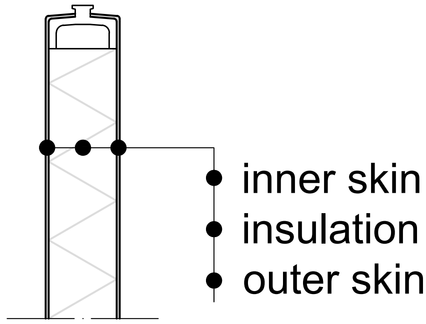

fig. 2. Diagram of the layering of a sandwich panel. Drawing by the author.

century. The first sandwich panel was created by the Forest Product Laboratory in Madison, Wisconsin, USA[18]. Only after the war, in 1952, the first commercially produced sandwich panel was introduced on the market[19]. Rigid foam insulation became an important group of materials for the core of the panels in the 1960s[20]. From the 1970s onwards, storey-high sandwich panels with external layers of concrete made sure that facades retrieved back their load-bearing function[21]. In the 1980s, sandwich panels were used on a large scale[22].

The development and use of sandwich panels started after the Second World War. Europe was largely destroyed and the

15 Takashi Kameda et al., 'Asbestos: Use, Bans and Disease Burden in Europe', *Bulletin of the World Health Organization* 92, no. 11 (2014): 792, https://doi.org/10.2471/BLT.13.132118.

16 See for instance the conservation of Umlauftank 2, Berlin, as described in Steffen Obermann, 'Do Modern Materials Need a New Conservation Approach?', *ICOMOS–Hefte Des Deutschen Nationalkomitees* 73 (2020): 103.

17 Bob Witman, 'Naoorlogse bouwmaterialen zijn uit de tijd, maar alsjeblieft, niet alles slopen, zeggen deze kenners', Boeken, *de Volkskrant* (Amsterdam), 23 July 2024, accessed 1 July 2025, https://www.volkskrant.nl/boeken/naoorlogse-bouwmateria

18 M. Panjehpour et al., 'Structural Insulated Panels: Past, Present, and Future', *Journal of Engineering, Project, and Production Management* 3, no. 1 (2013): 2, https://doi.org/10.32738/JEPPM.201301.0002; Ryan E. Smith, *Prefab Architecture: A Guide to Modular Design and Construction* (John Wiley & Sons, 2011), 142.

19 Panjehpour et al., 'Structural Insulated Panels', 3; Smith, *Prefab Architecture*, 142.

20 Panjehpour et al., 'Structural Insulated Panels', 3; Smith, *Prefab Architecture*, 142.

21 Wessel de Jonge, 'Gevelbekleding - Principes', in *Bouwmaterialen, 1940-1990: Vernieuwing, Constructie, Toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024), 144.

22 Ronald Stenvert, 'Bouwen in een nieuwe tijd', in *Bouwmaterialen, 1940-1990: vernieuwing, constructie, toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024), 47–48.

need for houses and other buildings was high. In Germany, 39% of the built area was destroyed, in the city of Hamburg 48% of the buildings was destroyed[23]. In 1947-48, the Marshall plan was developed by foreign minister of the United States George C. Marshall. The plan provided financial aid and resources, of which a part was destined to the construction sector in the various European countries[24]. The influence of the Marshall plan on the reconstruction of Europe is debated, as reconstruction already initiated before the plan, and the plan initially consisted mainly of loans intended to purchase food from the United States[25].

The change from a war economy to a free-market economy in peace times did not occur seamlessly. For instance, the Korea War (1950-1953) caused sharp inclinations of construction material prices[26]. On the other hand, the steel and aluminium industry, after increasing their capacity for the war, had an overproduction in the first years after the war, favourable for the construction sector[27]. Also the foundation of the European Coal and Steel Community, helped to increase steel trade[28].

The reconstruction period was an era of faith in technology and the future. European nations developed rigorous reconstruction plans, often visually appealing[29]. The ideas of the Congrès International d'Architecture Moderne (CIAM) were *en vogue*. Several countries set up plans to develop new towns and cities according to the modern ideal of the rational city, in which the functions living, working, transportation and recreation were separated[30]. Also in existing cities, like Rotterdam or beforementioned Hamburg, the idea was often to start with a tabula rasa to create a variant of this ideal city[31]. This was possible due to the damage after the war.

Over the course of the reconstruction period, this idea changed. A group

23 Peter Larkham, 'Conserving the Post-Second World War Reconstruction: A Contentious Idea', *Occasional Papers in the Historic Built Environment*, 2022, 2; Fred C. Iklé, 'Reconstruction and Population Density in War-Damaged Cities', *Journal of the American Institute of Planners* 16, no. 3 (1950): 133, https://doi.

24 Stenvert, 'Bouwen in een nieuwe tijd', 24.

25 Jeffry M. Diefendorf, 'Reconstructing Devastated Cities: Europe after World War II and New Orleans after Katrina', *Journal of Urban Design* 14, no. 3 (2009): 379, https://doi.

26 Stenvert, 'Bouwen in een nieuwe tijd', 25.

27 Ibid.

28 Ibid.

29 Larkham, 'Conserving the Post-Second World War Reconstruction', 62.

30 Bob Colenutt and Sabine Coady Schaebitz, 'Post-War New Town Heritage – Debates, Tensions and Prospects', *Occasional Papers in the Historic Built Environment*, 2022, 9; Eric Paul Mumford, *The CIAM Discourse on Urbanism, 1928-1960*, 1. MIT Press paperback ed (MIT Press, 2000), 209.

31 Jeffry M. Diefendorf, 'Urban Reconstruction in Europe After World War II', *Urban Studies* 26, no. 1 (1989): 134, https://doi.

of young architects, part of the tenth congress of CIAM (1954), came to be known as Team X, and they opposed the separation of functions and the large plans that the modernists of CIAM proposed[32]. The congress of Otterlo, CIAM '59, was the last meeting organised and is often considered the end of modernism in architecture[33].

This era of faith in technology and the future abruptly ended in the first years of the 1970s. The 1972 report Limits to Growth by the Club of Rome caused architects to realise that there was no endless supply of oil[34]. Also the 1973 oil crisis contributed to the desire to save energy and insulate facades[35]. At the same time, the crisis raised the price of plastic building materials to extends that would no longer make it economically feasible for use in mass housing construction[36]. It meant a change for the materialisation of sandwich panels, which often had an external blade of plastic. On the other hand, however, the new focus on energy saving was favourable for the building system, which by definition has a core of insulation material.

A large part of the building stock in European countries was constructed after the Second World war. In the European Union, 80,80% of the building stock was built during this period, in Italy, the share is 78,54%[37]. Almost half of the total amounts of buildings was constructed between 1946 and 1989[38]. A large part of the built environment, the world we live in, is shaped by these buildings and they form the scenery in which a lot of Europeans grew up.

The heritagisation process of works of the second half of the Twentieth Century, however, is not yet completed in most of Europe. In some countries or regions, there is no minimum age for buildings to be enlisted as monuments, but the process happens in batches[39]. In many states, on the other hand, a minimum age of a building of 50 or 70 years applies[40]. But especially when it comes

32 Stenvert, 'Bouwen in een nieuwe tijd', 41; Mumford, *The CIAM Discourse*, 241–44.

33 Mumford, *The CIAM Discourse*, 265.

34 Wim Zeiler, 'Dutch Efforts Towards a Sustainable Built Environment', in *Sustainability, Energy and Architecture* (Elsevier, 2013), 1, https://doi.org/10.1016/B978-0-12-397269-9.00001-3.

35 Michael A. Tomlan, 'Introduction: Building Modern America: An Era of Standardization and Experimentation', in *Twentieth-Century Building Materials : History and Conservation*, by Thomas C. Jester (Getty Conservation Institute, 2014), 9.

36 Sara Duisters, 'Kunststof Dromen: Gevels van Glasvezelversterkt Polyester in Nederland', *Bulletin KNOB*, 9 December 2023, 62, https://doi.org/10.48003/knob.122.2023.4.808.

37 European Commission, 'EU Building Stock Observatory - Database,' Data set, March 28, 2025, *https://building-stock-observatory.energy.ec.europa.eu/database/*. Data from 2020.

38 Ibid.

39 For instance in the Netherlands or in Flanders (see resp. Erfgoedwet or Onroerenderfgoedbesluit)

40 Robert Pickard, 'A Comparative Review of Policy for the Protection of the Architectural Heritage of Europe', *International Journal of Heritage Studies* 8, no. 4 (2002): 351, https://doi.org/10.1080/13527250220000 37191e; Bastien Couturier, 'Vers la protection du patrimoine postmoderne: Étude des mesures conservatoires d'édifices en France, en Italie, en Espagne et au Royaume-Uni', *Cahiers de la recherche architecturale, urbaine et paysagère* 21 (2024): 9, https://doi.org/10.4000/12x4v.

to buildings that could be considered 'post-modern', not many are enlisted. For instance, Spain, Italy and France have no or almost no enlisted buildings in which the term 'post-modern' (or a variant hereof) is mentioned in the description[41]. Even though this method of merely searching for this term can be considered far from an exhaustive research, it is concerning that important Twentieth Century works from architects like Aldo Rossi, Renzo Piano and Carlo Scarpa are not enlisted[43].

Furthermore, the research on the topic of building materials from the 60s, 70s and 80s of the last century is scarce and scattered. Research on for instance construction materials from the Italian fascist era is collected in the interesting monograph *Materiali autarchici* [autarchic materials] by Sara Di Resta, Giulia Favaretto and Marco Pretelli (2021, Padova: il Poligrafo). The handbook *Twentieth-century Building Materials* (Thomas Jester, 2014 (1995), Los Angeles, CA: the Getty Conservation Institute) focusses more on materials from an earlier period: the Modernist era. Another monograph, *Bouwmaterialen 1940-1990* [Building materials 1940-1990] by Kees Somer and Ronald Stenvert (2024, Rotterdam: nai010) has an extensive description of the history and uses of many building materials from the second half of the Twentieth Century in the Netherlands, but lacks information on restoration or conservation.

The focus of this thesis will therefore be restoration of sandwich panels in buildings from the years 1960-1990. The choice to limit the research to a period of time and not to a certain style is both practical and ideological. First of all, the beginning of the timespan 1960-1990 corresponds roughly to the introduction of sandwich panels on a commercial scale. Buildings from after 1990 will most probably not be restored yet.

Secondly, the focus on a time period is a clear choice

41 Couturier, 'Vers la protection du patrimoine postmoderne', 4–8.

to avoid semantic discussions about postmodernism and related styles. Sandwich panels are used in buildings from various styles, and choosing only postmodernism would limit the research to a great extend.

In the first chapter, the history of sandwich panels will be discussed in more detail. Using scientific literature and advertising in contemporary professional literature, the main manufacturers and the materials they employ will be identified and critically evaluated. Key works using sandwich panels will be discussed.

The second chapter will focus on the materials used, their conservation problems and preservation interventions. The first generation of buildings with sandwich panels has already been restored, to various degrees of conservativeness. This chapter will elaborate the different conservation problems that were encountered and their (probable) causes. The main sources will be restoration reports, restoration handbooks and scientific literature.

The last chapter will discuss different case studies to demonstrate a variety of solutions for the conservation problems of sandwich panels. Cases are taken from different European countries and the panels used are constructed in various materials. The case studies will be studied using scientific literature and archival material. The aim is to critically analyse the interventions and measures.

The process of patrimonialisation is not neutral, and neither is restoration or conservation[42]. It is a so called "*actum* di architettura"[43], an act of architecture. A creation of something new and a design process in which choices are made. It is therefore crucial to gain and systemise scientific knowledge. This is the fundament of making informed decisions on the safeguarding and restoration of the built legacy.

42 Maria Adriana Giusti, 'Criteri Di Patrimonializzazione Del Contemporaneo Tra Ricerca e Tutela', in *Il Diritto Alla Tutela : Architettura d'autore Del Secondo Novecento*, by Gentucca Canella et al., Architetti Italiani Del Novecento (Angeli, 2019), 104.

43 Ibid., 101. Italics MT.

1. History of sandwich panels

The twentieth century is a century of great innovations in architecture and the construction industry. For ages, buildings were built using the same palette of materials: mainly stone, brick and wood. The introduction of iron and later steel during the Industrial Revolution meant a change of paradigm. In a relatively short time, large parts of the built environment were now constructed in 'new' materials. The elements that construct these buildings continue to decrease in size, which makes 'newer' heritage relatively vulnerable[44]. The study of materials and innovations helps architects and other professionals who take care of the built heritage to understand the significance of certain buildings and building elements. It is a crucial step in the restoration and conservation process.

1.1. Development by Jean Prouvé

One of the first works that can be considered to have a sandwich panel façade is the Roland Garros club house at

fig. 3. Construction of the club house of Roland Garros Aerodrome. Photo Cohen and Hubert 2014.

44 Bernard Furrer, 'La pelle dell'edificio storico', in *Riuso del patrimonio architettonico*, ed. Bruno Reichlin and Accademia di Architettura, I quaderni dell'Accademia di Architettura Mendrisio / Università della Svizzera Italiana, AAM (Silvana Edtioriale [u.a.], 2011), 46.

the Buc aerodrome (Eugène Baudouin and Marcel Lods, façade technique by Jean Prouvé, Buc (France), 1937)[45]. Jean Prouvé (1901-1984) was trained as a blacksmith in Paris and had his own atelier when he met Baudouin and Lods[46]. They had the ambition to built vacation homes from modular elements. Their first building as a group was the air club canteen. It used to steel sheets that formed a panel that was connected to a steel frame (fig. 3). There was no insulation between the panels. This 'first' panel could be considered a kind of 'proto-sandwich panel'. The two architects and the engineer continued working together in several project and developed architecture with light panels that could be prefabricated[47].

A second work by the triumvirate that meant a step in the development of the sandwich panel was the Maison du Peuple in Clichy (France, 1935-40, fig. 4). The structure was used as a flexible space in which both the market and cultural events took place[48]. The main spaces could be converted from a market to a theatre or cinema in a relatively short time. For this design, Prouvé developed a structure of two metal sheets, folded together at the edges for stiffness and ease of assembly, filled with a layer of asbestos and fibreglass. Wire mattress springs space the panels and ensure the stiffness[49]. These panels are commonly recognised as a starting point for the development of sandwich panels.

In later works, Jean Prouvé progressed by adding windows to the ready-made panels. For the building for the Fédération Nationale du Bâtiment (architects Raymond Gravereaux and Raymond Lopez, Paris, 1951), he developed a panel with a window and insulation (fig. 5)[50]. The assembly of the façade could be done by two men and a simple winch, as it's mass was only 92 kg, at a speed of one storey per day. It

45 Jean-Louis Cohen and Christian Hubert, *France: Modern Architectures in History*, Modern Architectures in History (Reaktion Books, 2014), 134; Mick Eekhout, 'Sandwichpanelen en Architectuur', Publikatieburo Bouwkunde, 1 December 1993, 10, https://resolver.tudelft.nl/uuid:824f6646-ac90-4179-9621-a83fb2fba368.

46 Philippe Dufieux et al., *La réhabilitation des façades légères dans l'habitat du XXe siècle, de l'étude à l'expérimentation* (BRAUP; UMR 5600 EVS CNRS; Les Grands Ateliers Innovation Architecture (GAIA / L'Isle d'Abeau); Les Compagnons du Devoir de Villefontaine; La chaire partenariale d'enseignement et de recherche 'Habitat du Futur'; UMR 1563 AAU; ENSA Lyon; ENSA Grenoble; Conseil syndical de la copropriété Les Cèdres; Régie Franchet; Association CARGO JP 44, 2021), 20.

47 Cohen and Hubert, *France: Modern Architectures in History*, 134.

48 Charlotte Ellis, 'Prouvé's People's Palace', *The Architectural Review* (London, United Kingdom) 177, no. 1059 (1985): 41.

49 Eekhout, 'Sandwichpanelen en Architectuur', 11–12; Ariela Katz, 'Building the Machine in the Workshop: The Maison Du Peuple of Clichy, 1935–1940', *The Journal of Modern Craft* 13, no. 3 (2020): 293–94, https://doi.org/10.1080/17496772.2020.1848390.

50 Rouven S. Grom and Andreas W. Putz, 'Renovating Modern Heritage: The Upgraded Façade of Commerzbank Düsseldorf', *Journal of Facade Design and Engineering* 10, no. 2 (2022): 60, https://doi.org/10.47982/jfde.2022.powerskin.4.

was the first aluminium façade on this scale in Europe[51].

fig. 4. Maison du Peuple, Clichy. Photo Cohen and Hubert 2014.

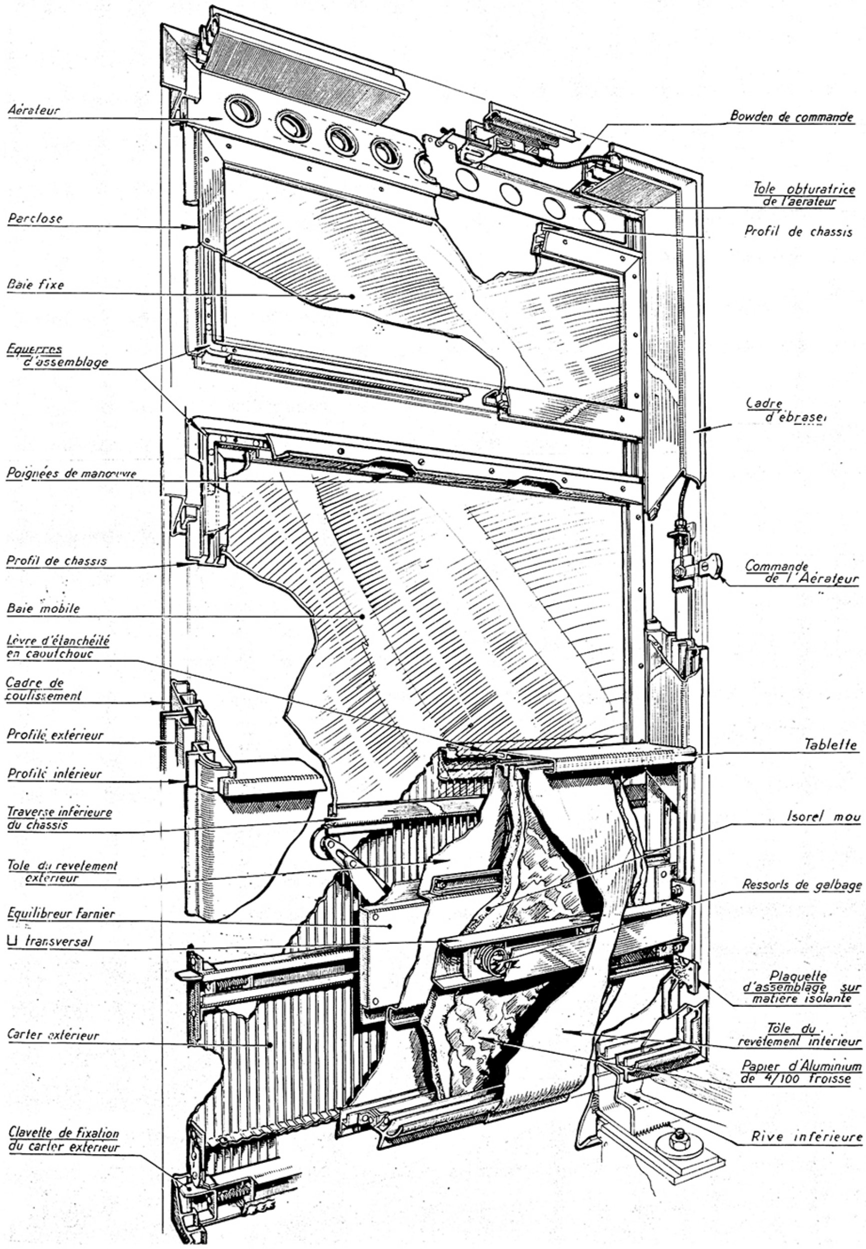

fig. 5. Facade panels of the building for the Fédération Nationale du Bâtiment (architects Raymond Gravereaux and Raymond Lopez, façade engineering Jean Prouvé, Paris, 1951). Drawing Fonds Jean Prouvé. Centre Pompidou – MNAM/CCI-Bibliothèque Kandinsky-Dist. RMN-Grand Palais.

51 Sébastien Cherruet, 'L'aluminium dans l'œuvre de Jean Prouvé, jalons et sources', *Cahiers d'histoire de l'aluminium* 4647, no. 1 (2011): 57, https://doi.org/10.3917/cha.046.0050; Marco Romanelli and Marco Visconti, 'Jean Prouvé: il progetto della facciata', *Domus* 706 (June 1989): 82.

1.2. Structural Insulated Panels in the United States

Parallel to this development by Jean Prouvé in France, was the development of the Structural Insulated Panel (SIP) in the United States. The first house with a self-supporting layered panel was developed by the Forest Product Laboratory of the United States Forest Service, in 1935 in Madison, Wisconsin[52]. Architect Frank Lloyd Wright experimented in the 1930s with his Usonian houses with façade panels with a timber core and battens on the external side[53]. His student, Alden B. Dow, wanted to design insulated buildings and replaced the timber core by a core of Styrofoam, in the 1950s[54]. This is generally considered the birth of the Structural Insulated Panel, which is a sandwich panel, that, contrary to Prouvé's panels, is load-bearing. Dow, brother of the founder of the chemical factory, started the production of SIPs in 1952 and further developed the product in the 1960s, for example with a rigid foam core[55]. In the 1960s other companies, like Koppers and Alside Home Program also produced SIPs and contributed to the development of the building system[56].

Also in the United States, architects experimented with aluminium panels. An aircraft company, Vultee Aircraft, hired Henry Dreyfuss and Edward Larrabee Barnes during the Second World War to develop prefabricated housing with aluminium panels which had a cellular core[57].

After the war, the Aluminium Company of America (Alcoa) commissioned new headquarters that were designed by architects Harrison and Ambramovitz (1953, Pittsburgh, PA, fig. 6)[58]. The structure resembles the panels Jean Prouvé designed for the Fédération Nationale du Bâtiment (see fig. 5).

52 R. F. Luxford, *Prefabricated House System Developed by the Forest Products Laboratory* (U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 1952), 1.

53 Michael J Obrien, 'Load-Bearing, Single-Wall Constructions from Shanties to Structural Insulated Panels', *Construction History* 28, no. 1 (2013): 60; Michael Morley, *Building with Structural Insulated Panels (SIPs): Strength and Energy Efficiency through Structural Panel Construction* (Taunton Press, 2000), 8, accessed 10 September 2025, http://archive.org/details/isbn_9781561583515.

54 Morley, *Building with Structural Insulated Panels (SIPs)*, 8.

55 Ibid.; Panjehpour et al., 'Structural Insulated Panels', 3.

56 Morley, *Building with Structural Insulated Panels (SIPs)*, 9–10.

57 Thomas C. Jester, 'Aluminum Finishes in Postwar Architecture', *APT Bulletin: The Journal of Preservation Technology* 46, no. 1 (2015): 43.

58 Ibid.

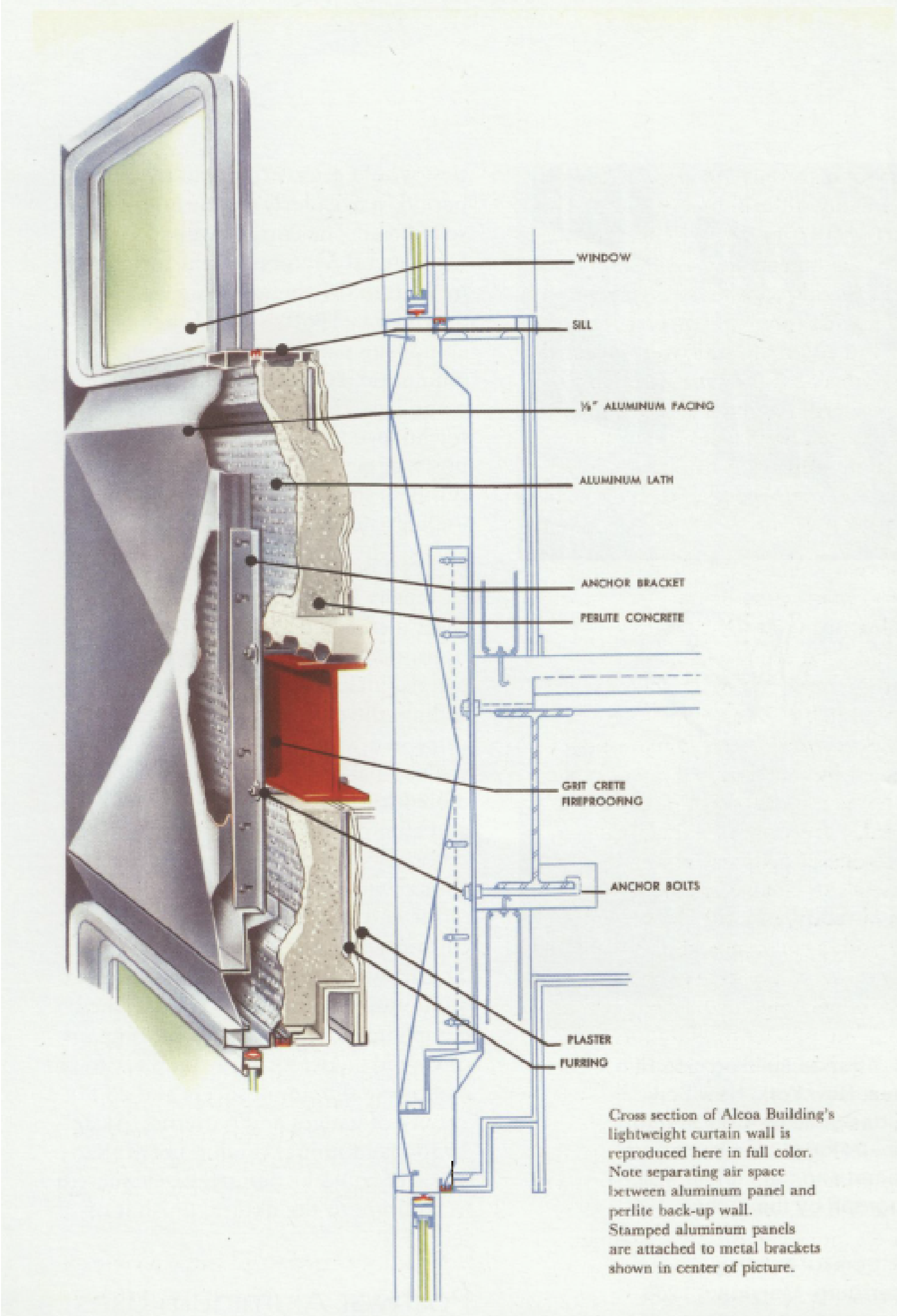

fig. 6. The façade panels of the Alcoa headquarters (Harrison and Abramovitz 1953, Pittsburgh PA). Drawing Thomas Jester 2015.

1.3. Post-war experimental housing

After the Second World War, the development of sandwich panels continued. Several designers and producers experimented with plastic houses . Between 1956 and the beginning of the 1970s, around 50 plastic houses were designed, the major part using glass-fibre reinforced polyester (GRP)[59]. Monsanto's House of the Future is a well-known example that stood in Disneyland Anaheim between 1957 and 1967 (fig. 7). It was designed by R.W. Hamilton and M. Goody, with A. Dietz responsible for engineering[60]. It was a collaboration between Disneyland, chemical company Monsanto and Massachusetts Institute of Technology (MIT), to demonstrate the future of housing[61]. The university and Monsanto were closely connected, as research financed by Monsanto and also often executed as a collaboration between MIT and the chemical company[62].

fig. 7. The Monsanto House of the Future in 1957. Photo IBK Archive.

The building was built up from a central concrete core, to which four wings in a cross shape were connected[63]. The wings were constructed in GRP, with a four inch honeycomb core[64]. They had a U-shape that formed the roof, the floor and the wall on one side[65]. Windows and translucent panels formed the other two sides of the wings. The architects tried to use new shapes, as this house should envision a radical break with the construction history in stone, brick and wood[66]. The building was for ten years a well-visited attraction and a showcase for new technology, but constructing buildings

59 E.M.L. Bervoets and F.C.A. Veraart, 'Bezinning, ordening en afstemming 1940-1970', in *Techniek in Nederland in de twintigste eeuw. Deel 6. Stad, bouw, industriële productie*, ed. Jan Willem Schot et al., with M.Th. Wilmink, Deel 6. Stad, bouw, industriële productie, Techniek in Nederland in de twintigste eeuw 6 (Stichting Historie der Techniek, 2003), 230.

60 Robert Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', *Docomomo Journal*, no. 66 (December 2022): 85, https://doi.org/10.52200/docomomo.66.10.

61 Carola Hein, 'The Global Petroleumscape', *Docomomo Journal*, no. 66 (December 2022): 12, https://doi.org/10.52200/docomomo.66.01.

62 Ibid., 10.

63 Edward Dimendberg, 'Transparenz und Taktilität. Plastik, Architektur und Kino in den 50er Jahren', *Paragrana* 17, no. 1 (2008): 252, https://doi.org/10.1524/para.2008.0014.

64 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 85.

65 Dimendberg, 'Transparenz und Taktilität', 252.

66 Ibid., 251.

out of plastic never became very popular.

Only a few years after the Monsanto House of the Future, emerged the first Dutch example of a plastic house: the Frits Bode House after it's commissioner, by architect Wim Pijpers in 1959[67]. The façade was constructed from two sheets of GRP with a cardboard honeycomb structure as a core[68]. The building tried to envision the future of construction.

Another experimental Dutch plastic house was developed by the airplane company Fokker in 1964. Fokker's Instant Home (fig. 8), as it was called, was designed by Egbert van Emden and used GRP panels around a PUR core[69]. Fokker used the experience from the aircraft industry, using honeycomb structures and fixing techniques[70]. The death of Van Emden stopped the development of the plan, which was intended as a do-it-yourself building kit[71], but Fokker started producing sandwich panels nonetheless[72]. Newspapers mention the development of housing with "plastic" sandwich panels[73].

fig. 8. Fokker's Instant Home. Photo Henk Hilterman – Nationaal Archief – Collection Spaarnestad Photo.

The Shell Plastic Laboratory, the Holland Building Corporation and the Dutch Petroleum Company (Nederlandse Aardoliemaatschappij, NAM) built two experimental GRP bungalows for NAM employees in 1967[74]. A steel structure carried sandwich panels from asbestos cement, with a core of PUR, and the exterior of the houses was finished by a mixture of epoxy and sand[75].

Perhaps the experimental plastic house

67 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 230; Duisters, 'Kunststof Dromen', 63.

68 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 230; Duisters, 'Kunststof Dromen', 63.

69 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 231; Duisters, 'Kunststof Dromen', 63.

70 Duisters, 'Kunststof Dromen', 64.

71 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 231.

72 Duisters, 'Kunststof Dromen', 64.

73 'Blokken Als Huizen Die Kunnen Meegroeien', *NRC Handelsblad* (Rotterdam), 4 July 1975, Delpher, accessed 29 September 2025, https://resolver.kb.nl/resolve?urn=KB-NRC01:000032475:mpeg21:a0148; 'Fokker Experimenteert Met Systeemwoning', *NRC Handelsblad* (Rotterdam), 17 May 1972, Delpher.

74 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 231.

75 Ibid., 232; Harry Lintsen et al., *The Plastics Revolution: How the Netherlands Became a Global Player in Plastics*, ed. B.P.A. Gales, trans. Tony Parr (Stichting Historie der Techniek, 2017), 81.

that was produced in the largest numbers is the Futuro by Matti Suuronen (1968, fig. 9)[76]. In 1965 the young Finnish architect gets the commission by school friend Antti Hiidenkari to design a light ski hut[77]. In the age of the space race, Suuronen designs a building that resembles a UFO on legs. On the steel legs rests a spherical building, with eight GRP shells forming the bottom and eight shells that make up the roof. The shells are built up from 3 mm GRP on the external side, 45 mm PUR foam (hardmoltoprene from Bayer AG) and 2 mm GRP internally, although dimensions differ for every individual building[78]. Sixteen larger PMMA windows are placed in the upper shells, and four in one of the bottom shells[79]. One of the bottom panels contains the door, that can be pulled down to create the entrance stairs, like in aircrafts[80].

The house was produced by the Finnish company Polykem Oy[81] and was also produced under license in ten different countries[82]. Polykem later produced, in cooperation with Suuronen, a series of houses under the title Casa Finlandia, of which the Venturo-House (1971) is the most well-known[83]. The mass-production of the Futuro, however, never actually started. It is estimated that 70 to 100 Futuros have ever been

76 Pamela Voigt, 'The Futuro: History, Design and Construction in Finland and the USA', *Docomomo Journal*, no. 66 (December 2022): 40, https://doi.org/10.52200/docomomo.66.05.

77 Sonja Bonin, 'Weltraumlook im Untertaunus', *Denkmal Hessen* 2024, no. 1 (2024): 46, https://doi.org/10.48630/DKHE.2024.1.104730; Anna-Maija Kuitunen, 'Futuro No. 001 : Documentation and Evaluation of Preservation Need' (Bachelor's thesis, Metropolia University of Applied Sciences, 2010), http://www.theseus.fi/handle/10024/15865.

78 Voigt, 'The Futuro', 45.

79 Ibid.

80 Kuitunen, 'Futuro No. 001', 8.

81 Bonin, 'Weltraumlook im Untertaunus', 46.

82 Marko Home and Mika Taanila, 'From Snowy Slopes to the Foot of Minarets. The Futuro's Journey from Finnish Ski Cabin to International Art Icon.', in *Futuro : Tomorrow's House from Yesterday = Tulevaisuuden Talo Menneisyydestä*, ed. Marko Home and Mika Taanila (Desura, 2002), 36.

83 Bonin, 'Weltraumlook im Untertaunus', 47; Hein, 'The Global Petroleumscape', 12; Home and Taanila, 'From Snowy Slopes to the Foot of Minarets.', 27; Kuitunen, 'Futuro No. 001', 14.

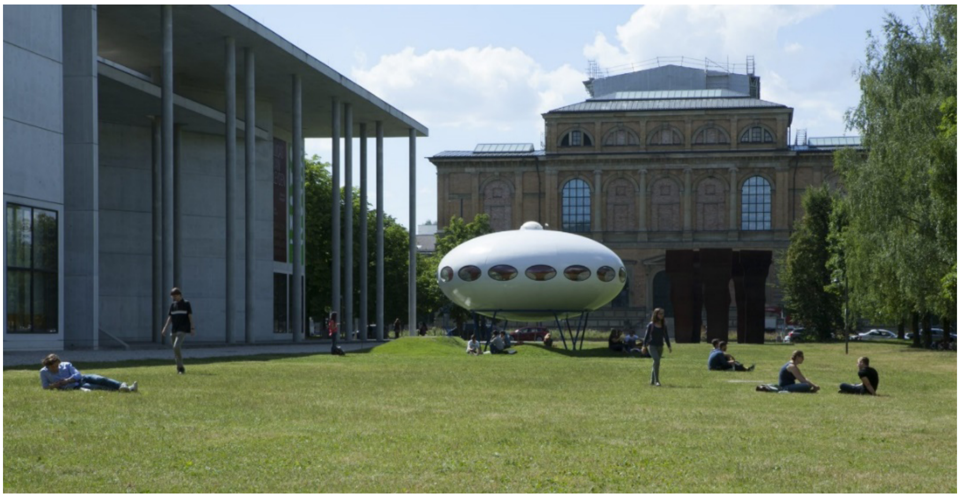

fig. 9. Futuro in Munich. Photo A. Laurenzo, Die Neue Sammlung.

produced, of which 65 ½ are known to still exist today[84].

The oil crisis of 1973 meant a stop for the further development of plastic buildings, like the Futuro. Oil prices increased sharply and the Futuro, that was already quite expensive, became unaffordable for the mass[85]. Furthermore were doubts raised on the quality of plastic construction materials, that became brittle and yellow with the passing of the years[86]. Besides that, plastic structures were considered a fire hazard[87]; public opinion on plastics as a construction material changed after a fire on 2 August 1973 in the Summerland Leisure Centre (Isle of Man), which was partly covered in PMMA[88]. The fire caused the death of 50 visitors and 80 were injured. The sentiment in society had changed and this plastic building was considered "outdated, ecologically questionable or too visionary"[89]. Plastics, like GRP and PMMA, did not become the construction material of the future.

1.4. Further developments in the last decades of the twentieth century

The progress that Jean Prouvé and the industry had, is well illustrated comparing his first 'proto-sandwich panel' and his later work, for example the Medical Faculty building of Rotterdam (1965-72), for which he designed the façades[90]. The Dutch government decided in May 1965 to found a new medical faculty in Rotterdam[91]. The government required that the first students could start their education already in September 1966, which lead to the design of a building with a flexible program of requirements[92]. The selected architect was the firm Van Embden, Roorda van Eysinga, Smelt, Wittermans, Choisy NV, that changed their name during the construction, in 1969, to OD 205[93]. To ensure a quick construction, it was decided to design a core in concrete, to be executed with a slinging frame, with

84 Voigt, 'The Futuro', 42–43. The half Futuro is vertically split and currently located in Frankfurt, Germany.

85 Home and Taanila, 'From Snowy Slopes to the Foot of Minarets.', 33; Mario Sánchez Samos, 'Arquitectura Sin Lugar. La Casa Futuro de Matti Suuronen', *Rita_*, no. 15 (May 2021): 115, https://doi.org/10.24192/2386-7027(2021)(v15)(06); Voigt, 'The Futuro', 41.

86 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 236–37.

87 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 85.

88 Bervoets and Veraart, 'Bezinning, ordening en afstemming', 236.

89 Voigt, 'The Futuro', 43.

90 Aanvulling Monumentenlijst Behorende Bij B&W-Besluit Nr. 10/8696 d.d. 7 September 2010, 10/8696, College van Burgemeester en Wethouders van Rotterdam, 2010 Gemeenteblad Rotterdam (2010).

91 H.J.J. Engel, 'Hoogbouw medische faculteit Rotterdam', *Bouw* 1972, no. 2 (1972): 38; I.C. Snijder, 'De bouw van de Medische Faculteit te Rotterdam', *Cement* 20, no. 6 (1968): 209.

92 Snijder, 'De bouw van de Medische Faculteit te Rotterdam', 209.

93 Aanvulling Monumentenlijst; Engel, 'Hoogbouw medische faculteit Rotterdam', 38; Snijder, 'De bouw van de Medische Faculteit te Rotterdam', 209.

fig. 10. Facade of the medical faculty of Rotterdam. Facade engineering by Jean Prouvé. Photo Fondation Jean Prouvé. Centre Pompidou – MNAM/CCI-Bibliothèque Kandinsky-Dist. RMN-Grand Palais.

a prefabricated concrete structure[94]. The façade, designed by Prouvé and his Compagnie Industrielle de Matériel de Transport (CMIT), consisted of prefabricated aluminium panels of 4 meter height (fig. 10), to match the storey height of the already existing Dijkzigt Hospital, to which the faculty was connected, and a width of 2,40 m, that matched the grid, which had a base of 1,20 m[95]. The panels form a skin that covers the columns that stick out of the façade, forming a relief. They have a structure of a galvanised, cold-rolled steel U-profile, to which a 3 mm white-lacquered aluminium outer blade, a 76 mm PUR core and a 1 mm white-lacquered steel sheet were connected[96]. Double-glazed windows on extruded aluminium profiles were included in the panels[97]. The sculptural façade with it's white lacquered panels is

94 Engel, 'Hoogbouw medische faculteit Rotterdam', 40; Snijder, 'De bouw van de Medische Faculteit te Rotterdam', 217.

95 Aanvulling Monumentenlijst; Engel, 'Hoogbouw medische faculteit Rotterdam', 40, 45.

96 Aanvulling Monumentenlijst.

97 Engel, 'Hoogbouw medische faculteit Rotterdam', 41.

considered very remarkable[98]. The façade was now fully prefabricated and the stiffness comes from the U-profile and the core.

Another building that illustrates the development of sandwich panels well is the Sainsbury Centre for Visual Arts (1974-78, Norwich) by Foster Associates[99]. This remarkable building houses the collection of Sir Robert Sainsbury and Lady Lisa Sainsbury, which they donated to the University of East Anglia in 1973[100]. The building has a structure of steel trusses, and a skin of ribbed aluminium sandwich panels, which are mounted to an extruded aluminium subframe, on the roof and the long façades[101]. The short façades were executed in glass.

Scholars Jones and MacLeod argue in their essay on museum architecture, that museum architecture both reflects and forms the social arrangements[102]. They use the work of sociologist Pierre Bordieu to state that museums, using formal aspects like the monumentality and social aspects like behaviour norms, create a distinction from everyday life and in- and exclude individuals[103]. Foster, with this museum, tries to challenge this process, by materialising the museum in a different way from traditional museum architecture. His steel trusses, however still monumental in their size, rather belong to industrial building types than to a museum. The same is valid for the sandwich panels. By using materials that *seem* mass-produced (the panels were in fact custom-made)[104] and also by the means of the program, which includes a coffee bar and meeting place, the architect sought to create a welcoming space, instead of a "formal gallery with its emphasis on art in isolation"[105].

A second museum that is important for the development of sandwich panels, is the Centre Pompidou by Renzo Piano and Richard Rogers (1971-1977,

98 Cherruet, 'L'aluminium dans l'œuvre de Jean Prouvé, jalons et sources', 62.

99 Norman Foster, 'Per l'arte All'università Di East Anglia', *Domus* 592 (March 1979): 13.

100 Foster + Partners, 'Sainsbury Centre Visual Arts | Projects', accessed 10 September 2025, https://www.fosterandpartners.com/projects/sainsbury-centre-for-visual-arts.

101 Eekhout, 'Sandwichpanelen en Architectuur', 23.

102 Paul Jones and Suzanne MacLeod, 'Museum Architecture Matters', *Museum and Society* 14, no. 1 (2017): 209, https://doi.org/10.29311/mas.v14i1.635.

103 Ibid., 210.

104 Foster, 'Per l'arte All'università Di East Anglia', 15.

105 Ibid., 16.

Paris). Although the sandwich panels are not as prominently present as in the façade of the Sainsbury Centre, the aim of the museum is the same: to step away from the traditional museum. The design brief contained a scheme of the different functions the new cultural centre was supposed to host – a library, a museum of modern art, a museum of contemporary art, amongst others – organised in a non-hierarchical way (fig. 11)[106]. The parking space was represented in the same size as the museum, and also the placement within the diagram revealed no hierarchy. The connections between the elements were the most important, as was also stated in the jury report[107]. The jury, of which beforementioned Jean Prouvé was the president, was critical of grand gestures and sculptural architecture, and was disappointed by the lack of innovative designs[108].

The design of Piano and Rogers, on the contrary, certainly was innovative, as it broke with monumental architecture, but used 'industrial' construction materials like glass and steel, but also the sandwich panels, and it left building services visible to the public. The floors of the building were flexible and dictated no particular hierarchy.

1.5. Conclusions

The Centre Pompidou has closed in 2024 for a renovation, already 24 years after the completion of the first renovation (1997-2000)[109]. Other works discussed in this chapter have already been renovated or restored, like several versions of Matti Suuronen's Futuro[110]. One could say that the "architecture of the future", due to its experimental nature, experiences conservation problems[111]. Systemisation of knowledge and a critical analysis of performed interventions are vital to safeguard important works of the built heritage for future generations.

106 Ewan Branda, 'The Forms of Bureaucracy at Centre Beaubourg', paper presented at ARCC 2017 Conference, Salt Lake City, UT, Architectural Research Centers Consortium (ARCC), 2017, 64.

107 Etablissement public pour la realisation du Centre Beaubourg, 'Concours international pour la réalisation du Centre Beaubourg - Rapport du Jury', July 1971, 7, Fondazione Renzo Piano, accessed 16 September 2025, https://www.fondazionerenzopiano.org/it/project/centre-georges-pompidou/#section-documents.

108 Ibid., 16–17.

109 Matthias Brenner, 'High-Tech Heritage: (Im)Permanence of Innovation', in *High-Tech Heritage: (Im)Permanence of Innovative Architecture*, ed. Matthias Brenner et al. (De Gruyter, 2024), 15.

110 Ashal Tyurkay and Uta Pottgiesser, 'From Deterioration to Revival: Approaches to the Conservation of Plastic Buildings', *Docomomo Journal*, no. 66 (December 2022): 78, https://doi.org/10.52200/docomomo.66.09

111 Brenner, 'High-Tech Heritage: (Im)Permanence of Innovation', 15.

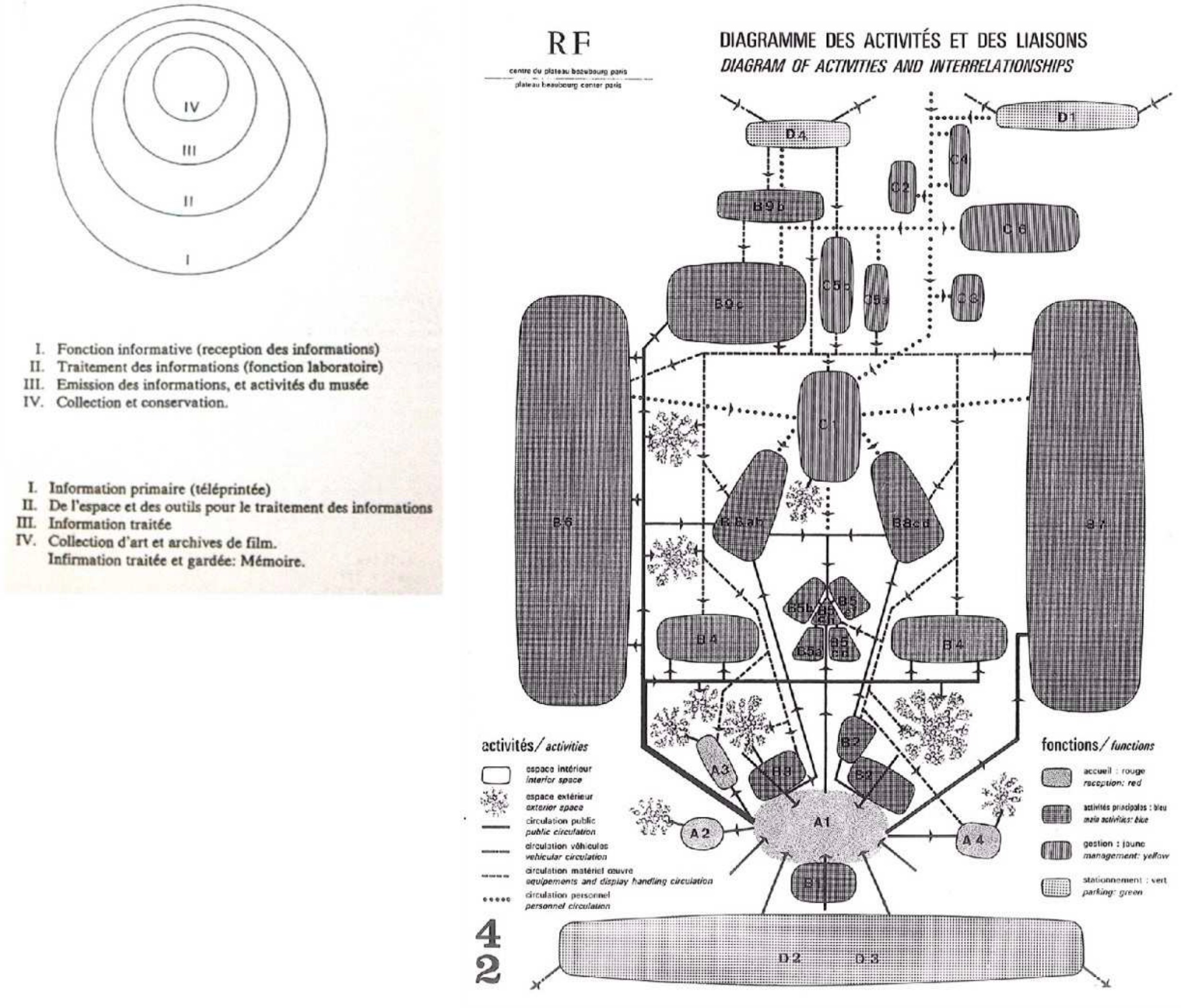

fig. 11. *Scheme from the design brief (1970). Illustration adapted from Branda 2017.*

2. Materials and producers

The main materials that form the outer blade of the sandwich panel can be categorised in plastics, metals , cement, asbestos and wood. The materials that form the core are often polymers, mineral wool, glass wool or natural materials. Many of these materials were developed in the twentieth century and became more common after the Second World War. Knowledge on several materials, is collected by Thomas C. Jester in his monography *Twentieth Century Building Materials: History and Conservation*. The authors of the different chapters discuss the use, production, decay and conservation measures of several innovative building materials from the Twentieth Century. In this standard work, the focus is on American building materials and American producers. Materials in Europe are comparable, but not exactly the same. However useful in many cases, lacunes are still present and not all knowledge on these materials has been systemised.

Another monography worth mentioning is *Claddings of buildings* by Alan Brookes (Longman Scientific & Technical, 1990), which came out at the end of the discussed period. It therefore gives an image of contemporary cladding technology, varying from production methods, to the discussion of incorrect detailing.

The systemised study of construction material producers serves two objectives. On the one hand, the study of companies and factories is a part of the history of a construction material. It is important from a perspective of innovation and trends in the construction industry. It illustrates changes in architectural history. On the other hand, is organised knowledge a tool for restoration and conservation.

The identification of manufacturers and their products can be of use determining which materials are employed.

Alongside testing, archival research is necessary to study the materials and to propose interventions. From construction documentation, the original structure, the history of the building and past interventions can be understood[114]. Comparing the structure to other buildings, the significance of the architecture can be comprehended[115].

Producers of building materials can be identified using advertisements in professional and academic literature . Also project documentation, in the same publication media, often mentions the products used. Periodicals like *Plastica*, a publication from the Dutch plastic industry[116], published summaries of the promotional documentation of construction products, alongside contact details of the producer[117], so that the reader could request more information from the producer, or to view the promotional material in a central place, like the library of a research institute. Furthermore, recruitment advertisement in general publications, like magazines and newspapers, proved to be a fruitful method for identifying major and local producers.

2.1. Metals

Out of the metals that can be employed for the skins of the sandwich panels, aluminium and steel are the most used. Although both are metals, the differences in production, conservation problems and possible interventions are numerous. Academic articles that document restoration interventions for buildings with metal façade panels form a good source of information, as do handbooks like *Metals* in the Practical Building Conservation series by English Heritage, written by Sophie Godfraind, Robyn Pender and Martin Bill (2012).

114 Ann Harrer and Paul Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', *MATEC Web of Conferences* 409 (2025): 2, https://doi.org/10.1051/mateconf/202540900006.

115 Ibid.

116 Duisters, 'Kunststof Dromen', 62.

117 See for instance: 'Ontvangen Brochures', *Plastica* 12, no. 12 (1959): 957.

2.1.1. Steel

As discussed previously, the first sandwich panels, which I called ‘proto-sandwich panels’ by Jean Prouvé, for the Roland Garros Aerodrome clubhouse (Eugène Baudouin and Marcel Lods, façade technique by Jean Prouvé, Buc (France), 1937) and the Maison du Peuple in Clichy (Eugène Baudouin and Marcel Lods, façade technique by Jean Prouvé, 1935-40), had a steel skin.

Steel sheets have been used as a cladding or roofing material for a substantial amount of time, but they rely on a protective layer, often paint, for corrosion-protection[118]. Another option for protection against corrosion is galvanising, which is the process of dipping the steel sheet, forming layers of alloys, of which the innermost contains mostly iron, and the outermost is pure zinc[119].

Another method of protection for steel sheets is electrostatic powder coating. Thermo-hardening polyester or polyurethane powders are electrically charged and sprayed onto the steel sheet, that forcefully attracts the powder as it would be oppositely charged[120]. The panel is then heat-cured.

In 1913 Harold Brearley found out that an alloy of chromium and carbon steel has a microscopically thin film on the surface of the steel, mainly containing of chromium oxide, that formed a protective layer against the corrosion of the iron in the steel[121]. Cladding or roofing of stainless steel was expensive at the time of introduction, but after the Second World War, prices decreased and the material was used as an alternative to the labour-intensive process of regularly repainting regular steel sheets[122].

Several companies were active in the field of steel sandwich panel productions. Examples of companies from the UK include Metecno, which used a two-colour-coated steel sheets with a

118 Alan Brookes, *Claddings of Buildings* (Longman Scientific & Technical, 1990), 179; Arja Källbom and Gunnar Almevik, ‘Maintenance of Painted Steel-Sheet Roofs on Historical Buildings in Sweden’, *International Journal of Architectural Heritage* 16, no. 4 (2022): 538, https://doi.org/10.1080/15583058.2020.1808910.

119 Sophie Godfraind et al., eds, *Metals*, Practical Building Conservation (English Heritage Ashgate, 2012), 128.

120 Brookes, *Claddings of Buildings*, 176–78.

121 Godfraind et al., *Metals*, 109.

122 Ibid., 110.

fig. 12. Lloyd's of London (Richard Rogers Partnership, 1986). The steel sandwich panels are used in the service towers. Photo RSHP.

polyisocyanurate core[123], and Briggs Amasco, which produced their panel Perfrisa, that consisted of two layers of 0,5 mm galvanised steel and a foamed PUR core[124].

An example of a building that has a façade from stainless steel sandwich panels is the Lloyd's office in London (Richard Rogers Partnership, 1986)[125]. In these headquarters of the bank, elements like the structure, elevators and ducts are clearly visible from the outside (fig. 12). The building communicates a transparency, after a period the bank struggled with scandals and losses, a contemporary critic wrote[126]. The sandwich panels were used as a means to create a high-tech building, to communicate an image to the general public[127]. The placement of the building services in plain sight made sure they were easily replaceable, as they had the shortest service life, according to Rogers[128]. In fact, the building had many defects and several elements of the building were on the nomination to be changed

123 Brookes, *Claddings of Buildings*, 167.

124 Ibid., 163.

125 Wilfried Wang, 'Richard Rogers Partnership Edificio Lloyd's, Londra', *Domus* 680 (February 1987): 37.

126 Ibid., 30.

127 Loïse Lenne, '1980s London: A Laboratory for Contemporary High-Rise Architecture. The Case of the Richard Rogers Partnership', *Built Environment* 43, no. 4 (2018): 494, https://doi.org/10.2148/benv.43.4.481.

128 Ibid.

already in the first decade after the completion of the structure[129].

The main deterioration mechanism of steel sandwich panels is corrosion. In the presence of water, the iron can react with oxygen to form rust[130]. Corrosion is therefore an irreversible chemical process. The presence of chlorine, for instance in marine environments, can increase the speed of oxidation[131]. Rust has a larger volume than steel and can therefore also mechanically damage a sandwich panel[132].

Important other factors that increase the risk of corrosion are poor maintenance, which causes protective layers, a patina or an applied protection, to break, allowing water to come in contact with the steel[133], and the contact with alkalis or metals that are lower on the galvanic table, like lead, nickel and copper[134].

Another threat to the structural integrity of steel sandwich panels is delamination between the skin and the core, caused by stresses of differences in thermal expansion between the outer and the inner skin[135]. Especially on the sun-exposed side of buildings, attention should be paid to the detailing of the panels, evading this kind of deterioration by choosing light colours, using different materials for the inner and outer blade, by choosing a sufficiently strong adhesive, and/or by limiting the size of the panel[136].

Regular cleaning for removing surface dirt can be done by rinsing the surface with warm water and a mild soap[137]. The use of abrasives or scratching the surface should be avoided. Corrosion can be treated in the same manner, using abrasives when necessary[138]. Waterjetting techniques at a low pressure can also be considered, as they have been proven effective to remove dirt and corrosion, but keeping paint layers intact on large metal heritage objects[139]. Oils and grease, for instance from fingerprints, can be removed

129 Georgios Eftaxiopoulos, 'Innovation Ad Infinitum: Lloyd's of London and the Cost of Flexibility', in *High-Tech Heritage: (Im)Permanence of Innovative Architecture*, ed. Matthias Brenner et al. (De Gruyter, 2024), 93.

130 Godfraind et al., *Metals*, 134.

131 Ibid., 137.

132 Ibid., 135.

133 Ibid., 148.

134 Ibid., 137; Robert Score and Irene J. Cohen, 'Stainless Steel', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (McGraw-Hill, 1995), 70.

135 Brookes, *Claddings of Buildings*, 173.

136 Ibid.

137 Score and Cohen, 'Stainless Steel', 70.

138 Ibid., 70–71.

139 Joseph Sembrat et al., 'Conservation of Historic Metals by Waterjetting Techniques', *Journal of Architectural Conservation* 11, no. 3 (2005): 123, https://doi.org/10.1080/13556207.2005.10784956.

using acetone, xylene, isopropyl alcohol, methyl alcohols or mineral spirits[140]. Rinsing the surface after cleaning is necessary, to avoid leaving a film on it. Scratches do not form a danger to the structural integrity of the panel and treatment by repolishing is likely to do more harm than good[141].

When repainting is necessary, the type of preparatory cleaning is dependent on the proposed new coating. Modern paints require all previous coatings to be removed, usually blast-cleaning, which is evidently irreversible[142]. Repainting of disassembled panels is easier than on-site painting, but has implications for the dismantling and transport[143]. The choice of paint depends on the budget, working conditions, compatibility and the maintenance[144]. For sandwich panels specifically, a durable paint is essential. The amount of surface that needs maintenance is usually large and disassembly can not be a part of daily maintenance, requiring a paint to last longer.

Replacement of (parts of) stainless steel sheets is possible when other options are exhausted[145]. A replacement piece can be welded into an existing skin, or the outer skin can be replaced completely.

When durably protected, steel is a material with little conservation problems. Incorrect detailing and lack of maintenance, however, cause serious risks for the structural integrity of the panels. Cleaning is possible using non-specialist materials, and corrosion, however irreversible, can often be treated.

2.1.2. Aluminium

The 'father of the sandwich panel', Jean Prouvé, constructed his first panels in steel. After the Second World War, the engineer started experimenting with aluminium panels[146]. Aluminium is a metal that is present in large quantities on earth , but the extraction

140 L. William Zahner, *Steel Surfaces: A Guide to Alloys, Finishes, Fabrication, and Maintenance in Architecture and Art* (John Wiley & Sons, 2020), 229, accessed 21 October 2025, http://ebookcentral.proquest.com/lib/polito-ebooks/detail.action?docID=6369883.

141 Score and Cohen, 'Stainless Steel', 71.

142 Godfraind et al., *Metals*, 180.

143 Ibid., 186.

144 Ibid., 184.

145 Score and Cohen, 'Stainless Steel', 71.

146 Eekhout, 'Sandwichpanelen en Architectuur', 11.

of it is not an easy process[147]. The metal is not found directly, but in a double salt (potassium aluminium sulphate dodecahydrate, $KAl(SO_4)_2 \cdot 12H_2O$)[148]. The electrolytic process for purifying aluminium was developed at the end of the nineteenth century, but the material was widely used during the Second World War for the aircraft industry, improving the production process[149]. In Italy, aluminium was promoted as "the Italian steel", during the fascism, since aluminium – as opposed to iron – was found in Italian soil[150]. After the Second World War, aluminium became more widespread in the construction industry[151].

Aluminium can be cast and wrought, but most construction products are wrought. Extrusion is the most used for tubes and profiles, like window frames, handrails and trusses[152]. Aluminium sheets, which are used in sandwich panels, are formed by rolling. The sheets would then be formed using a 'brake press' and be welded[153].

There are several ways of protecting the aluminium from oxidation, of which anodisation is the most used[154]. In this process, the aluminium reacts with oxygen in an electro-chemical bath, forming a protective layer of aluminium oxide which stops the aluminium from further oxidation[155]. There are several ways to form a coloured patina during the anodising. Inorganic pigments are used for gold and bronze colours[156]. Metallic salts can be used for grey or gold finishing[157]. The process of integral or hard colouring, using organic acids, or the electrolytic colour process can produce durable black, bronze and grey finishes[158].

A large producer of aluminium sandwich panels was Hunter Douglas, that introduced the Luxalon panel in the beginning of the 1970s[159]. Two aluminium blades were placed around a PUR core. Other large producers were Schweizerische Aluminium

147 Godfraind et al., *Metals*, 323.

148 Stephen J. Kelly, 'Aluminum', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (McGraw-Hill, 1995), 47.

149 Godfraind et al., *Metals*, 326.

150 Sara Di Resta et al., *Materiali autarchici: conservare l'innovazione* (Il Poligrafo, 2021), 116–17.

151 Ronald Stenvert and Danielle Takens, 'Metaal', in *Bouwmaterialen, 1940-1990: vernieuwing, constructie, toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024), 159.

152 Kelly, 'Aluminum', 48.

153 Brookes, *Claddings of Buildings*, 147.

154 Jester, 'Aluminum Finishes in Postwar Architecture', 44.

155 Ibid., 44; Kelly, 'Aluminum', 48; Stenvert and Takens, 'Metaal', 160.

156 Brookes, *Claddings of Buildings*, 121; Jester, 'Aluminum Finishes in Postwar Architecture', 44.

157 Brookes, *Claddings of Buildings*, 121; Godfraind et al., *Metals*, 328.

158 Brookes, *Claddings of Buildings*, 121; Jester, 'Aluminum Finishes in Postwar Architecture', 44.

159 Brookes, *Claddings of Buildings*, 165; Luxalon, 'Il cento per cento', *Domus* 578 (January 1978): back cover; Stenvert and Takens, 'Metaal', 160–62.

(later also known as Alusuisse) with their panels Alocobond and Alucopan[160], and Aalberts[161], from the Netherlands. In Italy, the panel Alusicc was produced by Morteo Sicit[162], and in Germany the Aluminium Struktur Bau was developed, which was a construction system with aluminium sandwich panels[163].

A well-known example of a building with aluminium sandwich panels is the beforementioned Sainsbury Centre for Visual Arts, by Norman Foster (1974-78, Norwich, fig. 13). The profiled panels on the building, however, had to be replaced, less than ten years after the opening, since the phenolic resin in the core reacted with the outer blade of the panel[164]. The materials selected were simply incompatible. The replacement panels are unfortunately smooth, rather than profiled, giving them less character than the originals.

Apart from incompatible materials, also other conservation problems occur with aluminium sandwich panels. The deterioration of the aluminium oxide layer under the influence of acids, chlorides, sulphates, dirt, and high relative humidity makes the aluminium vulnerable to corrosion[165]. The protective patina gets porous and allows pure aluminium to corrode. Eventual dirt present prevents the aluminium from reacting

fig. 13. The Sainsbury Centre seen from the sculpture garden. The new panels are smooth instead of profiled. Photo Andy Crouch.

160 Brookes, *Claddings of Buildings*, 169.

161 'Beurskandidaat Aalberts Boekt 35 Pct. Meer Winst', *De Telegraaf* (Amsterdam), 4 September 1986, Delpher, accessed 3 October 2025, https://resolver.kb.nl/resolve?urn=d

162 Morteo Sicitt, 'Alusicc', *Domus* 430 (September 1965): after front cover.

163 'Prefabricated ABS System', *Domus* 534 (May 1974): 22–23.

164 Eekhout, 'Sandwichpanelen en Architectuur', 22; Edward Ford, 'The Theory and Practice of Impermanence', *Harvard Design Magazine*, no. 3 (1997), accessed 20 May 2025, https://www.harvarddesignmagazine.org/articles/the-theory-and-practice-of-impermanence/.

165 Kelly, 'Aluminum', 50.

with oxygen, reforming the oxidation patina[166].

The close presence of certain other metals forms a threat to the aluminium panels. When in contact with water and a metal that is higher on the galvanic table, the aluminium will emit an electron to the other metal, and slowly dissolve[167].

Another deterioration mechanism is the contact with mortars, concrete and plaster. The contact with these alkaline materials deteriorates the protective patina of the aluminium, hence forming a risk for the aluminium sheet[168].

The last conservation issue discussed is the mechanical stress caused by the differences in thermal expansion between the outer and the inner blade. If both blades have the same thermal expansion coefficient, the outer blade might expand more, due to solar radiation, causing stresses, by the difference in expansion[169].

The accumulation of dirt can be solved by using a mild soap and soft cleaning materials, for more resistant dirt, a moderate soap can be used[170]. Against acid pollutants or alkaline additives, a solvent-based degreaser can be used[171]. For heavy soiled powder-coated aluminium, white spirit is a suitable solution[172]. Cleaning products containing esters, ketones, alcohols, acids and alkalis are strongly discouraged as they will damage the surface[173]. Cleaning products can be applied with a nylon brush or optionally a very fine abrasive pad, cleaning strokes should be parallel to the direction of the grain of the sheet[174].

There is no consensus in academic literature on the use of abrasives. Some authors recommend the use of plastic abrasives at low pressure for the removal of a porous aluminium oxide layer[175]. In restoration/renovation practice, several buildings with aluminium façade panels have been cleaned by abrasives[176]. Other authors argue that the use of abrasives is damaging to aluminium panels[177]. The conclusion is that the use of abrasives

166 Ibid.

167 Godfraind et al., *Metals*, 324; Kelly, 'Aluminum', 50.

168 Kelly, 'Aluminum', 50; Lyndsie Selwyn, 'Aluminum: A Modern Metal in Cultural Heritage', in *Aluminum: History, Technology, and Conservation*, ed. Claudia Chemello et al. (Smithsonian Institution Scholarly Press, 2014), 8.

169 Brookes, *Claddings of Buildings*, 172.

170 Godfraind et al., *Metals*, 331; Kelly, 'Aluminum', 51.

171 Godfraind et al., *Metals*, 331.

172 Ibid., 331.

173 Ibid.; Kelly, 'Aluminum', 51.

174 Godfraind et al., *Metals*, 331.

175 Kelly, 'Aluminum', 51.

176 Grom and Putz, 'Renovating Modern Heritage', 66; 'Referenz: Briefzentrum Zürich Mülligen', Monopol Colors, accessed 15 July 2025, https://www.monopol-colors.ch/de/referenz/briefzentrum-zuerich-muelligen/.

177 Godfraind et al., *Metals*, 331.

should be discouraged and only be used if the deterioration is threatening the structural integrity of the panels and all other options are exhausted.

It can be concluded that aluminium sandwich panels can be very durable. The protective patina safeguards the material from corrosion. Several cleaning methods are available for superficial dirt. Incorrect detailing, however, such as contact with steel or alkalic materials, threatens the material and decay is irreversible and difficult to repair.

2.1.3. Findings

Metal sandwich panels are relatively durable, due to the protection layer that forms on aluminium, or because of designed protective mechanisms. Examples of these mechanisms for steel are the use of stainless steel, the use of a protective coating and galvanising. Aluminium can be protected using anodisation.

Corrosion and galvanic action are threats to both steel and aluminium. Correct detailing is important, avoiding contact between different metals.

Metal façades can be cleaned using mild detergents. The use of abrasives is discouraged.

2.2. Plastics

Several plastics are used to form the blades of sandwich panels. The main materials are glass-fibre reinforced polyester (GRP), polyvinyl chloride (PVC), polymethyl methacrylate (PMMA, also known as acrylate or by trade names like Plexiglas and Perspex), and high-pressure laminates (HPL, more often known by the commercial names like Formica, Arborite and Trespa)[178]. These materials have different properties and possible interventions differ.

178 Kees Somer and Matthew Tan, 'Kunststof', in *Bouwmaterialen, 1940-1990: vernieuwing, constructie, toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024), 168–71.

2.2.1. Glass-fibre reinforced polyester

Most often, GRP is used in the making of plastic sandwich panels. The material is a combination of a polymer and glass fibres[179]. Acrylics, vinyls, polyolefins, epoxy, polyurethane and polyesters are used as polymers, the latter one the most[180]. Often, additives are used, like fillers, catalysts, plasticisers, UV stabilisers, additives for colour retention, toughness, surface quality and protection against flammability[181].

An important Dutch architect who used GRP panels in his work is Jan Brouwer[182]. The Sony Distribution Centre in Vianen (1972, fig. 14), for example, clearly indicates the two functions of the building. The ground floor, used for storage, was executed in reinforced concrete, whereas the first floor, the office space, had a façade of bright yellow GRP sandwich panels with large windows[183].

In the handbook *Twentieth-century building materials: history and conservation*, edited by Thomas Jester (McGraw-Hill, 1995), Anthony Walker describes meticulously the production process, the conservation problems and conservation practices of GRP panels in architecture. Most other literature is oriented on the conservation of GRP sculptures in public space or sculpture gardens.

The production of GRP panels is done using one mould, called contact moulding, or machine moulding, requiring two matching moulds[184]. For

fig. 14. Sony Distribution Centre in Vianen. Photo Jan Brouwer.

179 Anthony J. T. Walker, 'Fiber Reinforced Plastic', in *Twentieth-Century Building Materials : History and Conservation*, by Thomas Jester (McGraw-Hill, 1995), 142.
180 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 85; Walker, 'Fiber Reinforced Plastic', 142.
181 Brookes, *Claddings of Buildings*, 35; Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 85; Walker, 'Fiber Reinforced Plastic', 142.
182 Eekhout, 'Sandwichpanelen en Architectuur', 16.
183 Duisters, 'Kunststof Dromen', 68.
184 Walker, 'Fiber Reinforced Plastic', 144.

contact moulding, the mould is treated with release agent, to prevent the GRP panel from sticking to the mould. Then a 4 to 5 millimetre gel coat is applied by a brush or spray. A fine glass tissue may be embedded in the gel coat, to prevent the reinforcing glass fibres, which are added to the following coat, from sticking out. A coat of resin is applied with a brush . This resin may contain pigments, fillers and UV stabilisers[185]. Hereafter, a glass fibre mat is pressed into the coat. The glass fibre mat can be impregnated (the so-called lay-up technique). The mat is consolidated with a roller or brush until saturated, to remove air bubbles. Further layers can be added and also openings for fixtures are spared out in this phase. The panel is trimmed and finished and then left for curing, by heat or by room temperature. Machine moulding directly places the resin and the reinforcement between two moulds, treated by two release films[186].

The production of GRP panels does not necessarily require expensive machinery and the manufacturing process is relatively simple, allowing many small companies to produce these panels[187]. Larger companies do exist, however. In the United States, the most-used GRP sandwich panels were the Sanpan panels, by Panel Structures (East Orange, New Jersey) and Kalwall panels, by the Kalwall Corporation (Manchester, New Hampshire), developed by engineer Robert Keller[188].

Also on the European market were several companies active. British producers are for instance, H.H. Robertson, Anmac, Brensal, Armshire Reinforced Plastics and Antech Plastics[189]. In Liège (Belgium) Isobelec developed the sandwich panel 'Plasticair', with skins of 1,7 mm GRP and a core of 30 mm honeycomb impregnated with polyester resin[190]. A French producer was the company Matra, which developed a GRP panel with a phenolic foam core[191]. Also

185 Brookes, *Claddings of Buildings*, 36.

186 Walker, 'Fiber Reinforced Plastic', 144.

187 Brookes, *Claddings of Buildings*, 47.

188 Walker, 'Fiber Reinforced Plastic', 144.

189 Brookes, *Claddings of Buildings*, 47.

190 'Ontvangen Brochures', 957.

191 Pierre Joly, 'Prefabbricazione in Francia - Il Problema', *Domus* 581 (April 1978): 2.

the Dutch company Vicon produced GRP sandwich panels at a certain time[192]. The latter two companies originally produced for the car and agrotechnology sector respectively.

In their paper , Sanneke Stigter, Lydia Beerkens, Henk Schellen and Sara Kuperholc (2008) assess the condition of Joep van Lieshout's (1964) *Mobile Home for Kröller-Müller* (fig. 15), a GRP sculpture in the form of a trailer home, in the collection of Museum Kröller-Müller (Otterlo, the Netherlands)[193]. The work is intended as sculpture, but the shape and the fact that it is exhibited outdoors, in the sculpture garden, cause the work to border between sculpture and architecture. The paper analyses the condition, the materials employed and the interventions performed.

Usually, dirt and organic material accumulates on the surface of the panels[194]. As long as the gel coat layer remains intact, this is not particularly harmful for the panels.

In more severe cases, erosion and UV exposure causes discoloration and attacks the gel coat of the GRP panels, causing microcracks[195]. When fibres are exposed, by capillary

fig. 15. Joep van Lieshout's Mobile Home in the sculpture garden of Museum Kröller-Müller. Image Museum Kröller-Müller.

192 Somer and Tan, 'Kunststof', 168.

193 Sanneke Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller: Outdoor Polyester Sculpture in Transit', *ICOM Committee for Conservation 15th Triennial Meeting New Delhi, Preprints Vol. I, September 22-26, 2008*, Allied Publishers Pvt Ltd, 2008, 237–43.

194 Walker, 'Fiber Reinforced Plastic', 146.

195 Lydia Beerkens and Frederike Breder, 'Temporary Art? The Production and Conservation of Outdoor Sculptures in Fiberglass-Reinforced Polyester', *Conservation Perspective: The GCI Newsletter* 27, no. 2 (2012): 14; Barbara Salvadori et al., 'Painted Fiberglass-Reinforced Contemporary Sculpture: Investigating Composite Materials, Techniques and Conservation Using a Multi-Analytical Approach', *Applied Spectroscopy* 70, no. 1 (2016): 181, https://doi.

action water enters the GRP, which allows freeze-thaw cycles to mechanically damage the panel and to leave a whitish bloom: so-called chalking (fig. 16)[196]. If the gel-coat is not intact anymore, the panel becomes sensitive to (photo-)oxidation and hydrolysis[197]. Within the cracks, mould can grow, causing biological decay[198]. In the case of Van Lieshout's *Mobile Home* the mould grew from the external side of the panel, through the internal side, where it was noticed by the researchers[199].

Dirt on the surface of the panel can be removed using soft brushes and cloths, in combination with water and neutral surfactants[200]. If the gel-coat is still intact, but shows discolouration or became dull, a fine abrasive (for instance diamond paste) can be used to restore colour and polish, sacrificing a thin layer of the gel coat, which usually has a thickness of 0,5 mm[201]. This is, however, an expensive intervention.

Often, secondary coatings should be applied[202].

fig. 16. Exposed glass-fibres in a GRP shell, with white chalking visible. Image Pizzigati & Franzoni 2021.

Suited materials for this intervention are for example a polyurethane clear coat[203], or a polyvinyl-based copolymer[204]. A reversible, but labour-intensive alternative could be a sacrificial wax layer, that would have to be reapplied twice a year[205].

Larger damages like cracks can be restored by cleaning the surroundings, sanding away the coat in the damaged area, with tapered edges and filling the lacune up with a resin filler or epoxy putty, if a more coarse result is necessary[206]. Usually, a primer is used between the original surface and

196 Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller', 238; Walker, 'Fiber Reinforced Plastic', 146.

197 Salvadori et al., 'Painted Fiberglass-Reinforced Contemporary Sculpture', 181; Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller', 239.

198 Salvadori et al., 'Painted Fiberglass-Reinforced Contemporary Sculpture', 181; Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller', 239; Walker, 'Fiber Reinforced Plastic', 147.

199 Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller', 239.

200 Beerkens and Breder, 'Temporary Art?', 14; Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 89.

201 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 90.

202 Ibid., 90.

203 Beerkens and Breder, 'Temporary Art?', 15.

204 Lydia Beerkens et al., 'Go with the Flow: Conservation of a Floating Sculpture from 1961 Made from Glass Fibre- Reinforced Polyester Resin', in *Plastics: Looking at the Future and Learning from the Past: Papers from the Conference Held at the Victoria and Albert Museum, London, 23-25 May 2007* (Archetype, 2008), 47, https://hdl.handle.net/11245/1.345418.

205 Lydia Beerkens, 'Matti Suuronen's "Futuro" - Prototype 1968 After 50 Years', *Docomomo Journal*, no. 66 (December 2022): 62, https://doi.org/10.52200/docomomo.66.07.

206 Stigter et al., 'Joep van Lieshout's Mobile Home for Kröller-Müller', 240–41; Walker, 'Fiber Reinforced Plastic', 147.

the intervention material, to distinguish between the elements[207]. When the crack is threatening the structural integrity of the panel, a backing strip and thicker laminate are usually necessary[208]. Holes should be cut away, washed with methyl ethyl ketone and a replacement section should be placed, with a proprietary adhesive[209].

2.2.2. Polyvinylchloride

Poly(vinylchloride) is a product of the polymerisation of vinylchloride. The polymer itself is not directly usable as it tends to break when exposed to light, but after the development of certain additives and a more controlled production process, PVC was made commercially available at the beginning of the Twentieth Century[210]. PVC is one of the most used plastics in the construction industry as it is used for piping, window frames and façade cladding. It may contain certain additives, such as UV-stabilisers and plasticizers. Unplasticized PVC (uPVC) façade panels are formed in a mould under vacuum[211].

An example of a façade with PVC sandwich panels is the building of a centre for the research of the sea for the chemical company Montedison, in Napoli, by Gregotti Associati (1978, fig. 17)[212]. The choice was made for non-corrosive materials, because of the aggressive environment. Furthermore, the PVC and other polymers employed in the façade reflected the area of expertise of the company[213].

The major part of the research on the deterioration and conservation of PVC is aimed at flooring[214] and art objects in museum collections[215]. The specific PVC employed in these fields, however, usually contains plasticizers. Art objects in museum collections usually suffer from the degradation of the plasticizers, which is not the case in uPVC used in façade cladding. The deterioration of the PVC

207 Walker, 'Fiber Reinforced Plastic', 147.

208 Ibid.

209 Ibid.

210 Lintsen et al., *The Plastics Revolution*, 26.

211 Somer and Tan, 'Kunststof', 168.

212 'Centro di ricerca Montedison a Portici, Napoli', *Casabella* (Milan, Italy) 43, no. 450 (1979): 18.

213 'Centro di ricerca Montedison', 18.

214 Kimberly A. Konrad and Micheal A. Tomlan, 'Vinyl Tile', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (McGraw-Hill, 1995).

215 See for instance "POPART (Preservation of Plastic ARTefacts in museum collections)". n.d. Archived 26 April 2025, at https://web.archive.org/web/20250426160736/http://popart-highlights.mnhn.fr/index.html

fig. 17. The research centre in Napoli. Photo Censimento delle architetture italiane dal 1945 ad oggi.

polymers, on the other hand, remains comparable.

One of the main deterioration processes for PVC is chemical, under the influence of UV light. UV-stabilisers degrade over time and then the polymer itself deteriorates[216]. The process of dehydrochlorination, in which H and Cl molecules detach from the polymer and form HCl, creates sequences of conjugated double bonds (C=C) in the polymer, which absorbs UV and visible light, causing the PVC to appear yellow (fig. 18) [217]. The decomposition of PVC under UV furthermore causes free radicals to oxidate, forming alcohols, ketones and aldehydes[218]. Rain washes away these components, eroding the material and removing the gloss[219].

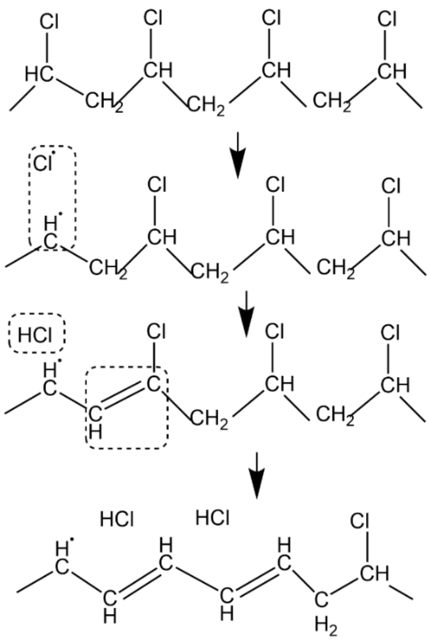

fig. 18. Dehydrochlorination of PVC. Image Saad et al. 2025.

216 Marzieh Riahinezhad et al., 'Critical Review of Polymeric Building Envelope Materials: Degradation, Durability and Service Life Prediction', *Buildings* 11, no. 7 (2021): 6, https://doi.org/10.3390/buildings11070299.

217 Anthony L. Andrady et al., 'Photodegradation of Rigid PVC Formulations. I. Wavelength Sensitivity to Light-Induced Yellowing by Monochromatic Light', *Journal of Applied Polymer Science* 37, no. 4 (1989): 937, https://doi.org/10.1002/app.1989.070370408; James D. Isner and James W. Summers, 'The Appearance Retention Properties of Poly (Vinyl Chloride) Compounds during Weathering', *Polymer Engineering & Science* 18, no. 11 (1978): 905, https://doi.org/10.1002/pen.760181114; Konrad and Tomlan, 'Vinyl Tile', 243; Tjaša Rijavec et al., 'Damage Function for Poly(Vinyl Chloride) in Heritage Collections', *Polymer Degradation and Stability* 211 (May 2023): 1, https://doi.org/10.1016/j.polymdegradstab.2023.110329.

218 Andrady et al., 'Photodegradation of Rigid PVC Formulations', 940; Isner and Summers, 'The Appearance Retention Properties of PVC Compounds during Weathering', 906.

219 Isner and Summers, 'The Appearance Retention Properties of PVC Compounds during Weathering', 906; Konrad and Tomlan, 'Vinyl Tile', 243.

The process of dehydrochlorination is irreversible. Interventions should therefore be aimed at slowing the process down. The yellowing process can be slowed down by coating the PVC with antioxidants and UV absorbers[220].

2.2.3. High-pressure laminate

The material high-pressure laminate (HPL) is a composite that is produced from a base material, like wood fibres or impregnated (kraft) paper, that with synthetic resin form a sheet material, under high pressure and temperature (fig. 19)[221]. The sheets of base material are soaked in phenolic resin and then pressed together by a heated hydraulic press[222]. The polymers in the resin link together under the heat and pressure, forming a durable sheet. Depending on the smoothness of the pressure plate, the HPL becomes more or less glossy[223]. Colours and patterns can be used in a top layer of paper[224]. Apart from wood fibres and kraft paper, also other fillers like cotton fabric or asbestos felt can be used[225].

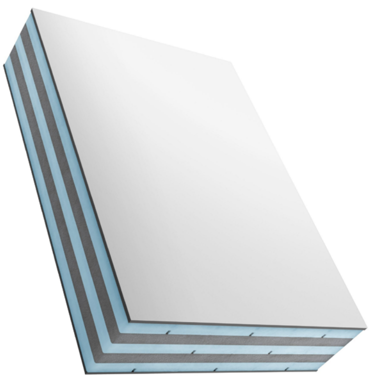

fig. 19. A HPL sandwich panel. Image Stadur Produktions.

The main producer of HPL sandwich panels was Formica, which used a core of expanded cork plates with HPL blades[226]. In northwestern Europe, the company Trespa produced HPL sandwich panels[227]. In Belgium the company Compagnie générale belge des isolants (Cogebi) produced HPL sheets under the name Panolux that could also be delivered as a sandwich panel[228].

HPL is a relatively durable material, but there are several degradation mechanisms that may impact the material. Water infiltration, mainly through

220 Chao Wu et al., 'Yellowing Mechanisms of Epoxy and Vinyl Ester Resins under Thermal, UV and Natural Aging Conditions and Protection Methods', *Polymer Testing* 114 (October 2022): 13, https://doi.org/10.1016/j.polymertesting.2022.107708; Napat Pattamasattayasonthi et al., 'Effects of UV Weathering and a CeO2-Based Coating Layer on the Mechanical and Structural Changes of Wood/PVC Composites', *Journal of Vinyl and Additive Technology* 17, no. 1 (2011): 15, https://doi.org/10.1002/vnl.20246.

221 Somer and Tan, 'Kunststof', 168–69; Anthony Walker et al., 'Decorative Plastic Laminates', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (McGraw-Hill, 1995), 127.

222 Walker et al., 'Decorative Plastic Laminates', 128.

223 Ibid.

224 Ibid.

225 Ibid., 128–29.

226 Somer and Tan, 'Kunststof', 171.

227 Ibid.

228 Stephanie Van de Voorde et al., *Post-War Building Materials in Housing in Brussels 1945-1975 / Naoorlogse Bouwmaterialen in Woningen in Brussel 1945-1975 / Matériaux de Construction d'après-Guerre Dans l'habitation à Bruxelles 1945-1975* (Vrije Universiteit Brussel, 2015), 359.

the edges forms a second threat to the integrity of the material, as the movement caused by the swelling and deswelling of the material can cause the surface to craze[229]. Light, particularly in the ultraviolet spectrum, causes the resin to turn yellow[230]. Biological decay is not common, unless the surface is not intact anymore[231]. A system of liquid penetrants and detectors can be used to examine the presence of cracks and crazes on the surface [232].

HPL can be cleaned using water, a non-ionising detergent and a soft brush[233]. A cellulose resin may fill up small damaged areas[234]. The yellowing may be slowed down using a protective coating with UV-absorbers[235].

2.2.4. Findings

It can be concluded that, when the outer layer is still intact, plastic sandwich panels are relatively resistant to various forms of decay. Their smoothness and closed structure makes them less vulnerable to biological decay. UV-radiation, on the other hand, is a serious factor in the deterioration. When the smoothness of the outer layer decreases and cracks form, the elements and biological agents further deteriorate the material. Restoration interventions are possible, especially for GRP panels, but for other materials, interventions are often limited to stabilisation of the decay.

2.3. Asbestos

Asbestos has been used since ancient times in the Western world and Asia for its insulating properties[236]. The term refers to a group of six types of naturally occurring mineral fibres that were used in several industries, among which the construction industry, for their properties like incombustibility, thermal stability and resistance to biodegradation[237]. Usually, asbestos is used in combination with a binder, like cement[238].

229 Walker et al., 'Decorative Plastic Laminates', 130.

230 Ibid.

231 Ibid.

232 Ibid., 131; Bing Wang et al., 'Non-Destructive Testing and Evaluation of Composite Materials/Structures: A State-of-the-Art Review', *Advances in Mechanical Engineering* 12, no. 4 (2020): 5, https://doi.

233 Walker et al., 'Decorative Plastic Laminates', 131.

234 Ibid.

235 Chao et al., 'Yellowing Mechanisms of Epoxy and Vinyl Ester Resins', 13.

236 Jan Kośny and David W. Yarbrough, 'Short History of Thermal Insulation and Radiation Control Technologies Used in Architecture', in *Thermal Insulation and Radiation Control Technologies for Buildings*, ed. Jan Kośny and David W. Yarbrough, Green Energy and Technology (Springer International Publishing, 2022), 28, https://doi.org/10.1007/978-3-030-98693-3.

237 Robert Virta, 'Asbestos', in *Kirk-Othmer Encyclopedia of Chemical Technology* (John Wiley & Sons, Ltd, 2011), 1, https://doi.org/10.1002/0471238961.0119020510151209.a01.pub3.

238 Eva Röell, 'Asbest', in *Bouwmaterialen, 1940-1990: vernieuwing, constructie, toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024), 172.

In 1900, Ludwig Hatchek developed at technique to mix asbestos pulp with cement and he introduced it on the market as Eternit in 1903[239] . Over the course of the years, many products have been developed, like Glasal (1957, see fig. 20), which was a asbestos cement panel that was cured in an autoclave and had a vitreous enamel top coat, that was very easy to clean[240]. The great diversity of products, in terms of texture, colour and properties, made asbestos a popular material for façades.

Already in 1924, the first messages about illnesses related to asbestos were published and in the 1960s and the beginning of the 1970s, the link between asbestos and certain types of cancer was scientifically proven[241]. In the 1980s and 1990s, asbestos was increasingly restricted and prohibited in several European countries and in 2005 the European Commission prohibited the extraction, processing and application of all asbestos in the European Union[242].

The asbestos cement of Eternit was produced in several European countries[243]. Producers who bought the patent from Hatchek also had the right to use the name Eternit for their companies[244]. The companies sold ready-made sandwich panels and asbestos cement panels to other companies that would produce their own sandwich panels. For asbestosis research, scholars have compiled lists of companies who produces asbestos, which makes identification of these materials easier[245]. Dutch companies include Mees' Bouwmaterialen from Groningen and Panelenindustrie Toelevering from Heerenveen[246] . Italian producers of asbestos cement included Eternit (Casale Monferrato, Rubiera dell'Emilia, Bagnoli and Priolo Gargallo), Società italiana amianto (Grugliasco), SACA (Cavagnolo) and Fibronit (Broni)[247]. French producers were amongst others Société Privas, that produced

239 S. Harmsma, *Asbest in Kaart. Historisch onderzoek Asbestgebruik en Methode Asbestkansenkaart*, with H.F.H.M. Mulder (ReGister, 2006), 43; Röell, 'Asbest', 172.

240 Röell, 'Asbest', 174.

241 Bruno Ziglioli, 'Il nemico invisibile. La fabbrica e la città in Italia tra memoria e rimozione: il caso dell'amianto a Casale Monferrato e a Broni', *Storia Urbana*, no. 154 (August 2017): 3, https://doi.org/10.3280/SU2017-154004.

242 Kameda et al., 'Asbestos', 794; Röell, 'Asbest', 172; Ziglioli, 'Il nemico invisibile', 3.

243 Röell, 'Asbest', 172.

244 Harmsma, *Asbest in Kaart*, 48.

245 For a list of Dutch producers see: Remko Houba and Vanessa Zaat, *Een oriënterend onderzoek in opdracht van het Instituut Asbestslachtoffers* (Nederlands Kenniscentrum Arbeid en Longaandoeningen, 2018), 20–23; For an Italian list, see: Ziglioli, 'Il nemico invisibile', 6.

246 Houba and Zaat, *Een oriënterend onderzoek in opdracht van het Instituut Asbestslachtoffers*, 20; 'Wij Ontvingen...', *Hafabo; Officieel Orgaan van de Vereeniging van Handelaren in Bouwmaterialen in Nederland* 45, no. 7 (1968): 359, Delpher.

247 Daniela Ferrante et al., 'Mortality among Asbestos Cement Workers: The Cohort of the S.A.C.A. Plant in Cavagnolo (Italy)', *BioMedical Statistics and Clinical Epidemiology* 2, no. 2 (2008): 172; Ziglioli, 'Il nemico invisibile', 6; 'Fibronit', Urban Visions, accessed 22 October 2025, https://www.urbanvisions.eu/fibronit/.

fig. 20. Glasal façade panels in a building in Amsterdam. Photo C.S. Booms.

sandwich panels with two layers of asbestos cement, a PUR core and an aluminium skin or epoxy coating on the outside[248], or Société Française d'Accessoires, d'Outillage et de Construction (SoFaCo), a construction company that built prefab schools from panels with asbestos wood fineer, polysterene and asbestos cement[249].

Asbestos is a form of problematic heritage. Preservation of heritage conflicts with the desire to minimise health risks. The extraction, processing and application in new constructions is prohibited, but there is often no obligation to remove existing and intact asbestos[250]. This leaves architects and heritage professionals with dilemmas

248 F.J. Freutel, 'Bezoek Aan de Foire de Paris', *Plastica* 11, no. 8 (1958): 601.

249 Ibid., 602.

250 Lorenza Fiumi, 'Problematiche legate alla conservazione di manufatti contenenti amianto realizzati nel novecento', *Italian Journal of Occupational and Environmental Hygiene* 16, no. 1 (2025): 2; Harmsma, *Asbest in Kaart*, 25; Dirk H.R. Spennemann, 'Removal or Preservation in Place? A Review of the Conservation Management Options for Asbestos Cement Sheeting in Heritage Properties', *International Journal of Building Pathology and Adaptation* 43, no. 6 (2024): 1413, https://doi.org/10.1108/IJBPA-04-2023-0039; Nancy Thiels, *Asbestveilig erfgoed. Afwegingskader voor het verwijderen van asbestmaterialen in beschermd onroerend erfgoed*, Afwegingskaders agentschap Onroerend Erfgoed (Agentschap Onroerend Erfgoed, 2025), 6, https://doi.org/10.55465/QLAX3123.

on how to treat asbestos when found in monuments.

Scholar Dirk Spennemann pleads in his paper for an approach to asbestos that is in favour of preservation of asbestos. According to his paper, sealants and paints are a safe way to seal asbestos fibres within the binder and an acceptable way to prevent erosion of the material, thus mitigating the health risk[251]. The presence of lichens, regularly seen as a form as biological decay, is in his paper regarded as positive:

lichens offer a physical barrier to the fibre detachment with a significantly lower (~30%) fibre loss than unprotected areas [...]. In addition, the chelating action of lichen metabolites progressively converts chrysotile asbestos into a non-fibrous amorphous material[252]

Spennemann regards the replacement of asbestos with a similar material as a loss of historic fabric, an option only to be considered when repairing and sealing alternatives are exhausted.

A similar stance is taken by Lorenza Fiumi, who specifically writes about the situation in Italy and also considers legal aspects. Apart from safety regulations regarding asbestos, Fiumi also discusses laws on cultural heritage, stating that encapsulating or confinement is preferred above removal of asbestos in the built legacy[253]. Building elements in asbestos are a testimony of innovation and style of the modern movement and should therefore be preserved as much as possible[254].

Nancy Thiels, on the other hand, describes a different point of view. In a report, written for the Agentschap Onroerend Erfgoed (Flanders Heritage Agency) in Belgium, she proposes an assessment framework for the removal of asbestos from monuments. This framework is connected to the Flemish government's plan to be "asbestos-safe" in 2040, which entails the

251 Spennemann, 'Removal or Preservation in Place?', 1414.
252 Ibid.
253 Fiumi, 'Problematiche legate alla conservazione di manufatti contenenti amianto', 4.
254 Ibid., 8.

removal most of the asbestos in Flanders and to monitor remaining asbestos that is not in a bad state[255].

If an asbestos element has no heritage value (architectural, artistic, industrial-archaeological or technological), and removal would give opportunities to improve, restore or to expose a previous 'layer', the framework advises to remove the asbestos[256]. Thiels favours the removal of asbestos, unless no health risk is present, *and* the element cannot be removed without endangering the material integrity or replacement is impossible because the element is extremely rare, unique or extraordinary[257]. If this is not the case, the asbestos should be replaced by a replica or a comparable material[258].

Noted should be that for public buildings in Flanders, asbestos roof and façade elements should always be removed[259]

Perhaps it's no coincidence that the Flemish policy is most oriented on removal of asbestos. Belgium had a large asbestos industry before the prohibition and exported large quantities to neighbouring countries[260]. Belgian scholars Hélène Verreyke, Doris Blancquaert and Joeri Januarius speak about 'dissonant' or 'difficult' heritage, which they define as a specific type of heritage with a connection with violence, war or traumatic memories[261]. They cite Gustave Wollentz who distinguishes 'toxic' heritage, that threatens certain values of society, like equal rights or health, which usually occur when heritage is treated inaccurately[262].

Heritage with asbestos forces society to reflect on the question: what do we want to pass on to future generations? Verreyke, Blancquaert and Januarius add to that question: who are *we*[263]? The Faro convention (Convention on the Value of Cultural Heritage for Society, Council of Europe, 2005) introduced the concept of heritage communities: organisations or individuals who value specific

255 Vlaamse Regering, *Nota Aan de Vlaamse Regering - Actieplan Asbestafbouw 2023*, VR 2024 2203 DOC.0360/1BIS (Vlaamse Regering, 2024), 2, https://themis.vlaanderen.be/files/65faaf4bca58fd000d000302/download?name=VR%20 2024%202203%20 DOC.0360-1%20Actieplan%20asbestafbouw%20-%20notaBIS.pdf&content-disposition=inline.

256 Thiels, *Asbestveilig erfgoed*, 33–36.

257 Ibid., 43.

258 Ibid., 41.

259 Ibid., 6.

260 Harmsma, *Asbest in Kaart*, 37; Hélène Verreyke et al., 'Doorgeven Aan Toekomstige Generaties? Asbest: Van Magisch Mineraal Tot Toxisch Erfgoed', *Volkskunde* 123, no. 3 (2022): 317.

261 Verreyke et al., 'Asbest', 320.

262 Ibid.

263 Ibid., 322.

aspects of cultural heritage which they want to preserve for future generations (art. 2.b). This implies stakeholders who have a positive relationship with the heritage in question[264]. Apart from the question if it is morally correct to hand over heritage with health risks to future generations, the authors specifically consider victims of asbestos who might not desire to keep the memory of asbestos alive.

Asbestos remains, 20 years after a general prohibition of production and use in the European Union, a topic of debate within the context of heritage. The technical solutions to preserve intact asbestos are well researched and described and also the legal possibility to preserve asbestos exists. It is vital for heritage communities – stakeholders and professionals – to determine on a case-by-case basis how to treat this toxic heritage.

2.4. Precast concrete

Since the development of the sandwich panel by Jean Prouvé in the middle of the twentieth century, the sandwich panel in Europe was usually not load-bearing. In the 1970s, precast concrete storey-high sandwich panels were introduced, which functioned as a part of the structure for vertical loads[265]. These panels allowed for a relatively quick and cheap construction and were therefore financially stimulated by various governments[266]. In Belgium for instance, construction costs of buildings with concrete sandwich panels were 10 to 15 % lower and the construction time was reduced by half or more, compared to construction with conventional technologies[267].

The appearance of the concrete sandwich panels could be influenced by aggregates such as gravel, pieces of brick or stone[268].

264 Ibid.
265 de Jonge, 'Gevelbekleding - Principes'; Van de Voorde et al., *Post-War Building Materials in Housing in Brussels*, 373.
266 Van de Voorde et al., *Post-War Building Materials in Housing in Brussels*, 385.
267 Ibid.
268 Ronald Stenvert, 'Gevelbekleding - beton', in *Bouwmaterialen, 1940-1990: vernieuwing, constructie, toepassing*, ed. Kees Somer and Ronald Stenvert (nai010 uitgevers, 2024); Van de Voorde et al., *Post-War Building Materials in Housing in Brussels*, 397.

Also the framework and the treatment of the surface was a tool for architectural expression. The finishing of the concrete could be smooth, washed acid-scoured or sandblasted[269]. Pigments can colour the concrete[270]. Another variant were panels with inlaid bricks on the outside, which were produced by placing bricks on the bottom of the mould and filling the mould with concrete[271].

In the United States, in 1938, thin precast concrete panels were installed for the first time as cladding, for the administration buildings at the David W. Taylor Model Testing Basin (Ben Moreell, U.S. Navy Bureau of Yards and Docks)[272]. These panels were of the Mo-Sai type, which had a galvanised welded mesh reinforcement and were vibrated to make the panel more compact[273]. The Mo-Sai Institute had a number of licensed manufacturers spread over the United States[274].

Around the same time, a different procedure for increasing the strength of concrete was developed by the company Schokbeton ('shocked concrete') in the Netherlands in 1935[275]. The concrete was consolidated by dropping the mould roughly 8 mm at a pace of circa 250 times per minute[276].

After the war, a third important innovation for concrete sandwich panels was developed, namely the glass fibre reinforced cement (GRC) panel. The material consists of ordinary Portland cement, silica sand and water, with alkali-resistant glass fibres for reinforcement[277]. Research in the late 1960s at the Building Research Establishment , which was a national research centre in the United Kingdom, developed a fibre using glass-containing zirconium oxide, after which Pilkington Bros further developed the product on a commercial scale in 1971 under the name Cem-Fil, by it's subsidiary Fibreglass Ltd[278].

There are three ways to produce GRC sandwich panels. The first method is to

269 Sidney Freedman, 'Architectural Precast Concrete', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (Getty Conservation Institute, 2014), 77; Van de Voorde et al., *Post-War Building Materials in Housing in Brussels*, 390.

270 Freedman, 'Architectural Precast Concrete', 77.

271 Van de Voorde et al., *Post-War Building Materials in Housing in Brussels*, 385.

272 Freedman, 'Architectural Precast Concrete', 77.

273 Ibid., 77–78.

274 Ibid., 77.

275 Stenvert, 'Gevelbekleding - beton', 153.

276 Freedman, 'Architectural Precast Concrete', 78.

277 Brookes, *Claddings of Buildings*, 70.

278 Ibid.

place an insulating core like polystyrene bead aggregate concrete and then spraying it with GRC[279]. Another option is to use panels of an insulating material like polystyrene and covering it with a slurry of GRC[280]. The last method is to create the GRC skins using casting, press moulding, slip forming or spraying, which are then filled by a insulating foam like polyisocyanurate, PUR or phenolic[281].

Producers of GRC panels were for instance Veldhoen Isolatic from the Netherlands and its subsidiary Fenox in the United Kingdom[282].

The headquarters in the United Kingdom for UOP Fragrances in Tadworth Surrey, were designed by Renzo Piano and Richard Rogers and contain GRC sandwich panels (fig. 21)[283]. The panels have a thickness of 152 mm and a polystyrene core[284]. They are sealed with neoprene gaskets[285]. Pigments in the concrete colour the panels in a bright yellow. The construction method was chosen to reduce costs and construction time[286]. The panels were mounted on a steel frame structure[287].

Conservation issues that precast concrete panels can suffer from are for instance freeze-thaw cycles, which cause concrete to detach[288]. This could lead to exposure

fig. 21. Bright yellow GRC sandwich panels in the façade of the UK headquarters of UOP Fragrances by Piano + Rogers. Photo RSHP.

279 Ibid., 77.
280 Ibid.
281 Ibid., 75–77.
282 Ibid., 78.
283 Ibid., 90; 'P+R Perfumery: Factory, Tadworth, Surrey Architects: Piano and Rogers', *The Architectural Review* 156, no. 934 (1974): 343; RSHP, 'UOP', RSHP, accessed 3 November 2025, rshp.com/projects/office/uop/.
284 'P+R Perfumery', 343.
285 Brookes, *Claddings of Buildings*, 90; 'P+R Perfumery', 343; RSHP, 'UOP'.
286 'P+R Perfumery', 338; RSHP, 'UOP'.
287 Brookes, *Claddings of Buildings*, 90; 'P+R Perfumery', 343; RSHP, 'UOP'.
288 Freedman, 'Architectural Precast Concrete', 78; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 1; Michiel Van Hunen, 'Beton - Schade', Rijksdienst Voor Het Cultureel Erfgoed, 30 September 2022, accessed 28 October 2025, https://kennis.cultureelerfgoed.nl/index.php/Beton_-_schade.

of reinforcement or other embedded steel elements, leading to corrosion which can cause mechanical stress and detachment of concrete[289]. Also staining of the concrete is possible[290]. The presence of chloride, due to impurities or by addition of calcium chloride to increase the curing speed, is a risk factor, as it reacts with the oxidation patina on the steel, causing pitting corrosion on the reinforcement, hence reducing the tensile strength[291].

The process of carbonatation is a risk for the structural integrity of reinforced concrete as well. Concrete naturally has a high pH, but infiltrating carbon dioxide can react with the hydroxides in the material, forming carbonates[292]. This decreases the pH, and makes the protective patina of the reinforcement vulnerable, causing corrosion. Carbonatation is a process that starts on the surface of the concrete and then slowly penetrates to the core, hence the reinforcement[293].

Saturated concrete is also at risk for the formation of ettringite, which is formed by the reaction of sulphate, present in additives or originating from outside the concrete, and minerals like aluminate and calcium, which are present in the cement[294]. This process is known as sulfate attack[295]. The cement will turn white and powder-like, and the bond with the aggregate will fail[296].

Another deterioration mechanism for the bond between the aggregate and the cement is the alkali-silica reaction (ASR). Alkalis present in the concrete react with silicas from additives, and the reaction product is an expansive crystalline gel, which causes the concrete to form a craquelure[297].

Incorrect detailing, such as the absence of dilatation joints that permit thermal expansion of the concrete, cause mechanical stresses that will eventually damage the concrete[298]. Also structural issues like overloading or incorrect

289 Freedman, ‘Architectural Precast Concrete’, 78; Ann Harrer and Jeffrey Caldwell, ‘Repairs to Concrete at the Pilgrimage Theatre in Los Angeles, California’, *APT Bulletin: The Journal of Preservation Technology* 48, no. 1 (2025): 52; Harrer and Gaudette, ‘Implementation of Conservation Approaches for Heritage Concrete’, 1.

290 Freedman, ‘Architectural Precast Concrete’, 78.

291 Van Hunen, ‘Beton - Schade’.

292 Catherine Croft et al., eds, *Concrete: Case Studies in Conservation Practice*, Conserving Modern Heritage (The Getty Conservation Institute, 2018), 191; Van Hunen, ‘Beton - Schade’.

293 Croft et al., *Concrete*, 13; Van Hunen, ‘Beton - Schade’.

294 Croft et al., *Concrete*, 194; Van Hunen, ‘Beton - Schade’.

295 Croft et al., *Concrete*, 194.

296 Van Hunen, ‘Beton - Schade’.

297 Prab Bhatt et al., *Reinforced Concrete Design to Eurocodes: Design Theory and Examples* (CRC Press, 2006), 15–16, https://doi.org/10.1201/b15266; Croft et al., *Concrete*, 191; Van Hunen, ‘Beton - Schade’.

298 Van Hunen, ‘Beton - Schade’.

dimensioning or natural disasters like earthquakes cause deterioration[299].

Furthermore, biological decay is possible which might cause corrosion of the reinforcement[300]. Atmospheric staining and efflorescence are further threats to concrete[301].

Specifically for GRC, the tensile and impact strength of the panel decrease over time[302].

Several destructive and non-destructive analysis methods are available to examine the concrete panel and the various types of decay. Petrographic analysis by stereomicroscopy can give more information on the composition of the concrete, such as the aggregate and the ratio cement-aggregate[303]. Carbonatation depth can be determined by the use of an indicator like phenolphthalein at new cracks[304]. Concrete is a base and should therefore turn purple. Transparent phenolphthalein indicates how deep the carbonatation process has penetrated (fig. 22).

Delamination and other imperfections can be detected by simply knocking the concrete with a hammer[305]. Compressive strength on the

299 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 1.

300 Mike Ford et al., 'Restoring Serenity: Conservation of Minoru Yamasaki's North Shore Congregation Israel', *Journal of Architectural Conservation* 27, nos 1–2 (2021): 109, https://doi.org/10.1080/13556207.2021.1933341; Freedman, 'Architectural Precast Concrete', 78; Guido Pietropoli et al., 'Brion Cemetry', in *Concrete: Case Studies in Conservation Practice*, ed. Catherine Croft et al., Conserving Modern Heritage (The Getty Conservation Institute, 2018), 181.

301 Freedman, 'Architectural Precast Concrete', 78; Ford et al., 'Restoring Serenity', 111.

302 Brookes, *Claddings of Buildings*, 87.

303 Ford et al., 'Restoring Serenity', 108–9; Michiel Van Hunen, 'Beton - Inspectie', Rijksdienst Voor Het Cultureel Erfgoed, 3 May 2023, accessed 28 October 2025, https://kennis.cultureelerfgoed.nl/index.php/Beton_-_inspectie.

304 Van Hunen, 'Beton - Inspectie'.

305 Ford et al., 'Restoring Serenity', 114; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 6; Van Hunen, 'Beton - Inspectie'.

fig. 22. Testing of carbonatation depth by phenolphthalein. The purple parts are not carbonatated. Photo C. van der Steen, Technoconsult Heeswijk.

surface can be tested by a Swiss or Schmidt hammer[306]. Ultrasound testing can give more detailed information on the strength, elasticity modulus, depth of cracks, and homogeneity of the concrete[307].

Cleaning of concrete is possible, but due to the fact that concrete is an inhomogeneous material with varying composition, laboratory and field tests are necessary to determine the adequacy of the proposed cleaning solution[308]. The gentlest cleaning materials and methods should always be preferred over more aggressive detergents. Dry scrubbing with a nylon brush or scrubbing with water and rinsing might already be effective[309]. Further methods of cleaning are low-pressure water spraying, water misting or moderate-to-high-pressure water washing[310].

The use of detergents and acids can be considered, but the manufacturer's instructions should be observed[311]. A biocide cleaner can – where allowed by environmental law – be used to remove biological growth[312], but steam cleaning can also be effective[313].

When protection is applied to surrounding concrete, an acid can be used to remove corrosion stains from the surface[314].

Aggressive acids or high-pressure washing should be avoided, as should the blasting of sand, ferrous aluminium silicate and other abrasives[315]. The use of these cleaning techniques will erode or dull the cement matrix[316].

Removal of coatings is possible by the use of one-part coating removal systems – one application for smooth textures, multiple for more coarse textures – and a low-pressure water rinse[317]. A brush can be used to apply the coating removal system in a coarse profile. Trial removals with various techniques and procedures should always be performed[318]. A high temperature and pressure and

306 Croft et al., *Concrete*, 194; Van Hunen, 'Beton - Inspectie'.

307 Van Hunen, 'Beton - Inspectie'.

308 Freedman, 'Architectural Precast Concrete', 79; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4.

309 Freedman, 'Architectural Precast Concrete', 79.

310 Ibid.

311 Ibid.

312 Ford et al., 'Restoring Serenity', 111.

313 Patrick Dillon and Stephen Douglas, 'National Theatre', in *Concrete: Case Studies in Conservation Practice*, ed. Catherine Croft et al., Conserving Modern Heritage (The Getty Conservation Institute, 2018), 175.

314 Ibid., 174.

315 Freedman, 'Architectural Precast Concrete', 79; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4.

316 Freedman, 'Architectural Precast Concrete', 79; Wolfgang H. Salcher, 'Gänsehäufel Swimming Facility', in *Concrete: Case Studies in Conservation Practice*, ed. Catherine Croft et al., Conserving Modern Heritage (The Getty Conservation Institute, 2018), 101.

317 Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 53.

318 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 6.

lower water volume device can also be considered[319].

Carbonatation is usually treated by removing the affected concrete and replacing it[320]. In the case of sandwich panels, this would mean that often the panel would need to be entirely replaced.

In the case of severe ASR or sulphate attack, the structural integrity of the panel is endangered because the bond between the cement and aggregates is weakened[321]. The chemical reactions are irreversible and stabilisation is the only option. Often limiting water penetration is an adequate solution[322]. Realkalisation is also possible by soaking the concrete with an alkaline solution[323].

For interventions in which parts of the concrete panel or entire concrete panels are replaced, a mock-up may be necessary to experiment with the suitable wood species or material for the formwork, the form-release agents, colouring agents, aggregate size and placement procedures[324].

fig. 23. Removal of concrete beyond the reinforcement to allow for removal of corrosion and for proper bonding with the replacement concrete. Photo Ann Harrer and Paul Gaudette.

The various characteristics can be used to both match the existing concrete, as to distinguish the intervention from the original material.

Other properties that need to be considered are the modulus of elasticity and the compressive strength[325]. Furthermore, tensile strength, bonding strength, permeability, porosity and water penetration can be considered[326].

The concrete of the repair area should be removed using hand tools, saw cutting or small electric chipping hammers, keeping in mind that vibrations could cause damage to undeteriorated concrete[327]. A limited part of the concrete that is still in

319 Stuart Tappin, 'Dudley Zoological Gardens', in *Concrete: Case Studies in Conservation Practice*, ed. Catherine Croft et al., Conserving Modern Heritage (The Getty Conservation Institute, 2018), 69.

320 Michiel Van Hunen, 'Beton - Onderhoud En Herstel', Rijksdienst Voor Het Cultureel Erfgoed, 23 June 2025, accessed 28 October 2025, https://kennis.cultureelerfgoed.nl/index.php/Beton_-_onderhoud_en_herstel.

321 Ibid.

322 Amy E. Slaton et al., 'Reinforced Concrete', in *Twentieth-Century Building Materials : History and Conservation*, ed. Thomas Jester (Getty Conservation Institute, 2014), 68; Van Hunen, 'Beton - Onderhoud En Herstel'.

323 Slaton et al., 'Reinforced Concrete', 69.

324 Croft et al., *Concrete*, 18; Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 53; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 3.

325 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 3; Van Hunen, 'Beton - Inspectie'.

326 Van Hunen, 'Beton - Inspectie'.

327 Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 54; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4.

good condition should also be removed, in order to achieve a well-prepared substrate[328]. The reinforcement should then be cleaned from corrosion and loose parts and subsequently be coated with a cementitious-based corrosion-inhibiting material (fig. 23)[329]. Also the exposed concrete should be cleaned from accumulated dirt and debris, to ensure a strong bond between the replacement concrete and the original material[330]. When protection is applied to the surrounding concrete, the use of sand-blasting and other abrasives can be considered[331]. When necessary, reinforcement should be installed[332]. The use of formwork is preferred over trowel-application, because it results in better long-term performance[333]. Trowel-applied interventions remain more visible after the restoration[334]. Curing is possible to reduce shrinkage, which could lead to separation from the original material, by covering the area with a polyethylene sheet[335].

Repairing on-site is also possible for GRC using the same technique, but for larger damages, restoration in a workshop is preferred[336].

For panels with steel reinforcement, the use of cathodic protection can be considered when corrosion severely damaged the precast panel. An anode would have to be connected to the reinforcement, forcing the steel to function as cathode, hence preventing the loss of electrons and thus corrosion[337]. A difference in potential protects the steel. A disadvantage of cathodic protection is that a large amount of fabric needs to be removed in order to install the system.

When paint needs to be applied, careful consideration should be given to the porosity, as the paint should always be more vapour-open than the concrete, to avoid moisture accumulation behind the paint[338]. A paint that has a low gloss and forms a thin layer allows the texture of the formwork to remain visible[339]. Other

328 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4.

329 Ford et al., 'Restoring Serenity', 109; Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 54; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4–5; Elisabeth Hinz and Andreas W. Putz, 'Concrete Repair in Heritage Preservation. A Review of Opposite Approaches at Antoniuskirche Basel and Liederhalle Stuttgart', *International Journal of Architectural Heritage* 19, no. 5 (2025): 820, https://doi.org/10.1080/15583058.2024.2427658.

330 Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 54; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 5.

331 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 5.

332 Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 54.

333 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 4.

334 Ford et al., 'Restoring Serenity', 109.

335 Harrer and Caldwell, 'Repairs to Concrete at the Pilgrimage Theatre', 55.

336 Brookes, *Claddings of Buildings*, 96–97.

337 Croft et al., *Concrete*, 191; Slaton et al., 'Reinforced Concrete', 68–69; Van Hunen, 'Beton - Onderhoud En Herstel'.

338 Van Hunen, 'Beton - Onderhoud En Herstel'.

339 Ibid.

considerations are the colour, gloss, watertightness, elasticity and the degree to which it can bridge cracks[340].

The use of a protective coating or penetrating sealer can be considered, however, it might also alter the appearance of the façade – an undesirable effect[341]. Generally speaking, hydrophobic impregnating is transparent and does not leave a film[342]. It should also be taken in consideration that the application of penetrating sealers is generally considered irreversible[343]. The protective layer should be more vapour-open than concrete[344].

Concluding, concrete sandwich panels are an innovation from the 1970s, although most developments that made this construction system possible were created around the Second World War. The sandwich panels, both with steel and glass fibre reinforcements do have a few conservation problems. Precast concrete panels with steel reinforcement are sensitive to corrosion, through various mechanisms. Glass fibre reinforced concrete loose tensile strength over the years. Interventions are often possible, but not in the case of carbonatation or severe alkali-silica reaction or sulphate attack. Replacement is in these cases often inevitable.

340 Ibid.

341 Ford et al., 'Restoring Serenity', 114; Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 6; Van Hunen, 'Beton - Onderhoud En Herstel'.

342 Van Hunen, 'Beton - Onderhoud En Herstel'.

343 Harrer and Gaudette, 'Implementation of Conservation Approaches for Heritage Concrete', 6; Van Hunen, 'Beton - Onderhoud En Herstel'.

344 Van Hunen, 'Beton - Onderhoud En Herstel'.

3. Case studies

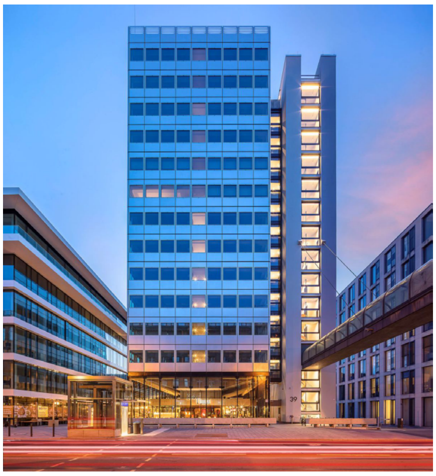

fig. 24. The aluminium sandwich panel facade of the Commerzbank in Düsseldorf. Photo Ralph Richter (HHP Architekten).

3.1. Commerzbank

The former headquarters of the Commerzbank in Düsseldorf (fig. 24) form an interesting and well-documented case study. The building was designed by architect Paul Schneider-Esleben and built between 1959 and 1962[345]. This office tower was peak-modernity when it opened, as it had Germany's first drive-in bank counter[346]. Not only the functioning of the building was innovative, also the façade by the Gartner company was the first of its kind, since it is considered the first completely prefabricated element façade in Germany[347]. The tower was enlisted as a monument of the state Nordrhein-Westfalen in 1998[348]. The building was renovated between 2016 and 2021 by HPP Architekten, and Bollinger & Grohmann for structural and façade engineering and is since then used as a hotel.

The external and internal blade of the sandwich panel were constructed of anodised

345 Grom and Putz, 'Renovating Modern Heritage', 59; Daniel Pfanner et al., 'Transformation Eines Pionierprojekts - Transformation of a Pioneering Project', *DETAIL* 63, no. 10 (2023): 79; Christian Rothkopf and Michael Roming, 'Sanierung Einer Denkmalgeschützten Hochhausfassade', *Fassade | Façade* 2022, no. 02 (2022): 45.

346 Grom and Putz, 'Renovating Modern Heritage', 47; Pfanner et al., 'Transformazion Eines Pionierprojeckts', 79.

347 Pfanner et al., 'Transformazion Eines Pionierprojeckts', 84.

348 Rothkopf and Roming, 'Sanierung Einer Denkmalgeschützten Hochhausfassade', 47.

aluminium (2 mm) (fig. 25). The aluminium is of the type AlMg3, which means it is an alloy of aluminium and 3% magnesium[349]. The core is composed of a paper air-comb honeycomb structure, filled with synthetic resin foam, the honeycombs were impregnated with phenolic resin, for moisture and fire retarding[350]. They were produced by the Douglas Air-Craft Corporation in Santa Monica (United States)[351]. At the vertical joints, continuous steel U-profiles, connected the sandwich panels to steel anchors, which were sunken into the concrete structure[352]. Gaskets for the joints and for the horizontal pivot windows were executed in neoprene[353].

After more than 50 years after the construction, the building in Düsseldorf was still in a good state, however, some signs of decay were present. The aluminium blades of the panels had signs of exposition to the weather[354]. The honeycomb structure within the panels was largely intact[355], although some edged of the panels delaminated and allowed water to penetrate the insulation layer[356]. The windows within the panels were single-pane.

Although the panels were largely intact, with little conservation issues, the renovation, where also the original façade engineer Gartner played a role in, had a large number of impactful interventions. The aluminium sheets were abrasively cleaned[357]. Because the honeycomb core displayed normal flammability, and because of changing energy demands, it was decided to replace the core of the panels by mineral wool (fig. 25)[358]. The window frames of the original pivot-windows did not allow the installation of insulation glazing, therefore, a new parallel-opening window was developed[359]. The panels were mounted on a new frame and resealed.

In the cavity, additional insulation was placed[360]. Also the neoprene gaskets in the joints between the panels were replaced by rubber variants, with a

349 P. Schneider-Esleben, 'Verwaltungshochhaus Der Commerzbank, Düsseldorf = Bâtiment Administratif de La Commerzbank à Düsseldorf = Administrative Building of the Commerzbank, Düsseldorf', *Bauen + Wohnen = Construction + Habitation = Building + Home: Internationale Zeitschrift* 17, no. 8 (1963): 347, https://doi.org/10.5169/seals-331661.

350 Grom and Putz, 'Renovating Modern Heritage', 63; Rothkopf and Roming, 'Sanierung Einer Denkmalgeschützten Hochhausfassade', 47.

351 Schneider-Esleben, 'Verwaltungshochhaus Der Commerzbank', 347.

352 Grom and Putz, 'Renovating Modern Heritage', 63.

353 Ibid., 63; Schneider-Esleben, 'Verwaltungshochhaus Der Commerzbank', 347.

354 Pfanner et al., 'Transformazion Eines Pionierprojeckts', 86.

355 Ibid.

356 Rothkopf and Roming, 'Sanierung Einer Denkmalgeschützten Hochhausfassade', 48.

357 Grom and Putz, 'Renovating Modern Heritage', 66.

358 Pfanner et al., 'Transformazion Eines Pionierprojeckts', 86.

359 Ibid., 87.

360 Nathalie Brum, 'Umnutzung des Commerzbank-Hochhauses, Düsseldorf', *Deutsche BauZeitschrift* 2021, no. 11 (2021), accessed 11 August 2025, https://www.dbz.de/artikel/dbz_Umnutzung_des_Commerzbank-Hochhauses_Dusseldorf-3699951.html.

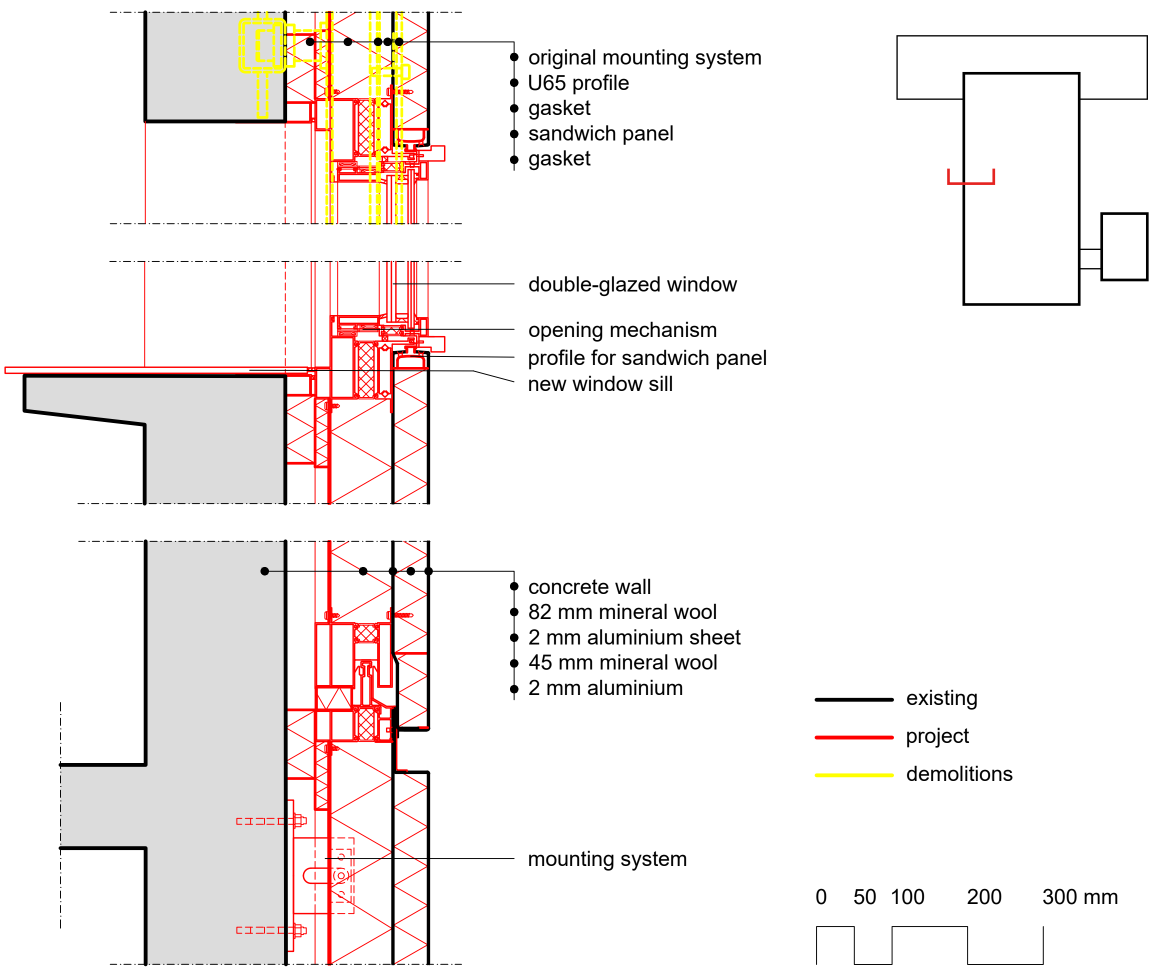

fig. 25. Section of the façades of the Commerzbank in Düsseldorf. Scale 1:10. Drawing Maarten Trietsch. Key plan adapted from Pfanner, Tarazi & Dönhoff 2023.

similar appearance[361]. Also the mounting system was replaced, as the existent system did not correspond with the drawings and was placed relatively irregular[362]. Lastly, the window sills were replaced, because the existing ones contained asbestos[363].

In conclusion, the Commerzbank tower looks relatively unchanged from the outside, except for the different way the windows open. Every element between the aluminium façade sheet and the concrete structure, from mounting system to insulation, on the other hand, has been replaced. The appearance remained, but the materiality almost entirely changed.

361 Grom and Putz, 'Renovating Modern Heritage', 66.

362 Ibid.

363 Schneider-Esleben, 'Verwaltungshochhaus Der Commerzbank', Fassadendetails-Konstruktionsblatt.

3.2. Briefzentrum Zürich-Mülligen

Briefzentrum Zürich-Mülligen is a building by architect Theo Hotz that was constructed between 1981 and 1985 in Mülligen, Switzerland[364]. Commissioned by the Swiss Post, it originally accommodated a parcel sorting centre and six duplex apartments for Swiss Post workers[365]. Appreciated for its futuristic design, the building was enlisted on a cantonal level in 2019[366]. Currently, the building is in use for mail sorting[367].

Located next to the railway leading to Zürich, the building originally had a mail railway station on the ground floor with fourteen tracks – a relict from when the Swiss Post largely invested in rail transport of mail[368]. The ground floor also accommodated public functions such as the receptions and desks, the upper floor housed the conveyor and sorting systems[369]. After the 2005-2007 reorganisation of the building, the Briefzentrum accommodates mainly truck transport, although a track on the North side can still be used for rail transportation[370].

The structure of the building is a combination of concrete for the lower floors and a steel framework for the upper floors (fig. 26)[371]. The façade, engineered by Geillinger AG, is built up from sandwich panels with a steel inner skin of 5 mm, a mineral wool core of 100 mm, a 70 mm cavity and a 3 mm aluminium outer skin[372]. The panels are 2,25 m wide[373]. The aluminium is of the type AlMg1.5, which indicates the magnesium content (1,5%) in the alloy. The panels are powder-coated[374]. They are stiffened by folding the edges and by the horizontal beads on the upper panels[375]. The panels have windows and ventilation outlets. The sculptural façade has a very elegant design for rainwater rundown.

The sandwich panel is connected to the structure with U-profiles. The

364 Matthias Brenner, *Innovative Envelope Design: Theo Hotz' High-Tech Construction for Zurich*, June 2024, 68, https://doi.org/10.3929/ETHZ-B-000712584; FBP, 'Postzentrum 8010 Zürich-Mülligen', *Schweizer Ingenieur Und Architekt* 103, no. 25 (1985): 645, https://doi.org/10.5169/SEALS-75835.

365 Brenner, *Innovative Envelope Design*, 68; FBP, 'Postzentrum 8010 Zürich-Mülligen', 645; M. Brenner et al., 'The Potential of Reverse Engineering and Digital Fabrication for the Repair of High-Tech Architecture', *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLVIII-M-2–2023 (June 2023): 307, https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-303-2023.

366 Kanton Zürich, Baudirektion, kantonale Denkmalpflege, 'Inventar Der Denkmalschutzobjekte von Überkommunaler Bedeutung', 13 September 2019, 1, accessed 15 July 2025, https://odb.zh.ch/odbwiki/mediawiki/files/pdfs/Schlieren-Inventar_32_1-festgesetzt_2019.pdf.

367 Brenner, *Innovative Envelope Design*, 68

368 Brenner, *Innovative Envelope Design*, 69; FBP, 'Postzentrum 8010 Zürich-Mülligen', 645.

369 FBP, 'Postzentrum 8010 Zürich-Mülligen', 645.

370 Brenner, *Innovative Envelope Design*, 68.

371 Ibid., 70; FBP, 'Postzentrum 8010 Zürich-Mülligen', 645.

372 Brenner, *Innovative Envelope Design*, 70.

373 Brenner et al., 'The Potential of Reverse Engineering and Digital Fabrication', 307.

374 Ibid., 307.

375 Brenner, *Innovative Envelope Design*, 70.

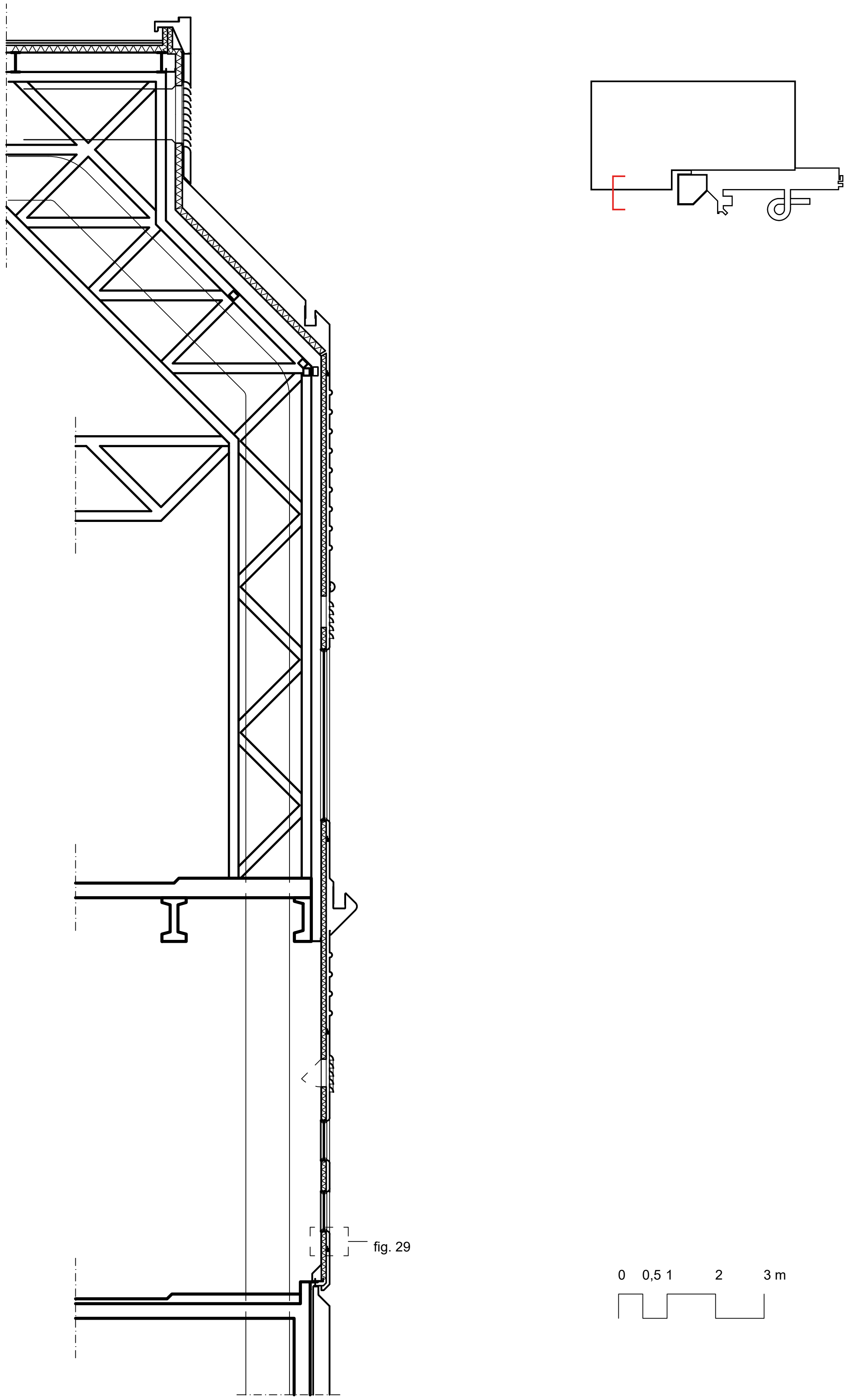

fig. 26. Façade section of the Briefzentrum Zürich-Mülligen. Drawing after Theo Hotz, elaboration by the author.

aluminium and steel parts are separated by gaskets, to avoid galvanic action. The windows are double panes. Between the panels, a layer of fire resistant insulation material is placed.

Between 2005 and 2007 the original architect Theo Hotz adapted the building internally to accommodate the new function of mail sorting centre[376]. The building was restored between 2016 and 2018, although research already started in 2014[377]. The renovation was lead by the real estate department of the Swiss Post[378].

Over time, the building had deteriorated. Due to chalking and loss of gloss, the grey façade lost its original appearance[379]. It suffered from biological growth and was soiled[380]. Although the panels were structurally intact, the appearance chanced over the course of the years; colour differences appeared between and within panels (fig. 27).

The powder-coating and embedded dirt particles were removed using abrasive cleaning[381]. The first step of this cleaning process was

fig. 27. Briefzentrum Mülligen before the restoration (2014). Photo Kanton Zürich, Baudirektion, kantonale Denkmalpflege, no. D100662_95.

to high-pressure clean the surfaces[382]. Then, the surfaces were cleaned with a neutral cleaner (Qualiprotec Reiniger N), using the abrasive side of a sponge[383]. The last step of cleaning was dry sanding, after which dust was removed from the surface and the panels were rinsed[384].

A new finishing layer was then applied (fig. 28). A grounding layer, epoxy with corrosion protection pigments, was sprayed on in a layer of 40 to 50 μm[385]. Lastly, a fluoropolymer paint layer was applied in a thickness of 30 to 40 μm, sprayed on easily accessible surfaces, and rolled on more difficult reachable surfaces[386]. Fluoropolymers are resistant to UV radiation and are chemically inert[387]. The insulation material remained untreated (fig.

376 Kanton Zürich, Baudirektion, kantonale Denkmalpflege, 'Inventar Der Denkmalschutzobjekte', 2.
377 Monopol Colors, 'Briefzentrum Zürich Mülligen'; Lionel Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz', *Applica*, no. 1 (2019): 17.
378 Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz', 17.
379 Ibid., 1.
380 Ibid., 16–17.
381 Ibid., 17.
382 Ibid.
383 Monopol Colors, 'Briefzentrum Zürich Mülligen'; Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz', 17.
384 Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz', 17.
385 Monopol Colors, 'Briefzentrum Zürich Mülligen'; Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz'.
386 Schlessinger, 'Riesige Metallfassade erstrahlt in neuem Glanz', 19.
387 María Teresa Molina et al., 'Protective Coatings for Metallic Heritage Conservation: A Review', *Journal of Cultural Heritage* 62 (July 2023): 107, https://doi.org/10.1016/j.culher.2023.05.019.

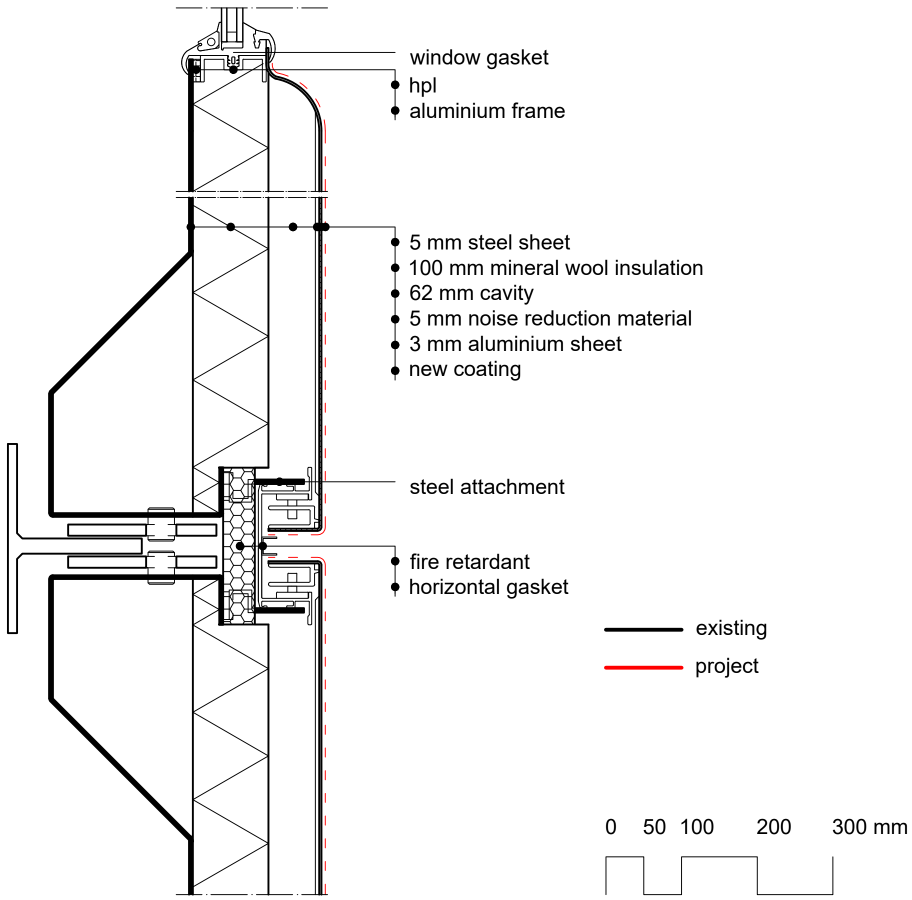

fig. 28. Horizontal section of the panels of the Briefzentrum Zürich-Mülligen. Scale 1:10. Drawing after Theo Hotz and Geilinger AG, elaboration by the author.

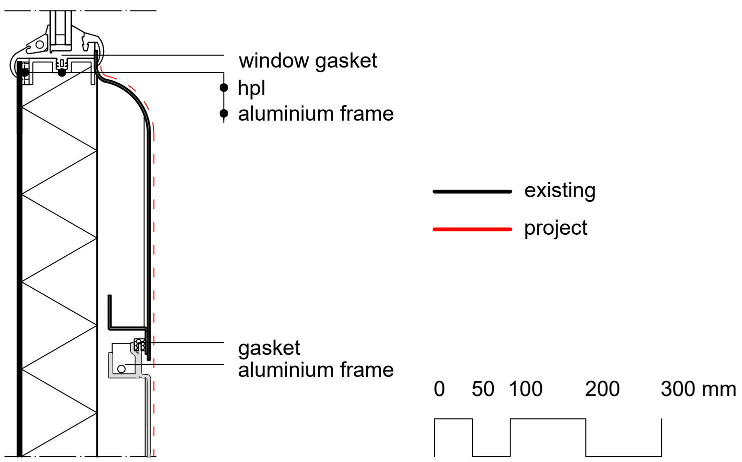

fig. 29. Vertical section of the façade of Briefzentrum Zürich-Mülligen showing the window frame and the aluminium attatchment frame. Scale 1:10. Drawing after Theo Hotz and Geilinger AG, elaboration by the author.

29). The restoration of the Briefzentrum entailed a removal of the powder-coated surface. This irreversible intervention allowed the façade to have a uniform appearance, but it also meant the loss of original fabric.

fig. 30. The Herman Miller factory around the time of the opening. Photo Nicholas Grimshaw Architects.

3.3. Herman Miller factory

The former Herman Miller factory was completed in 1976 and designed by Farrell & Grimshaw Architects (fig. 30)[388]. The furniture factory is located in Bath and was listed Grade II in 2013, meaning it is of special interest and worth preserving[389]. The building was transformed into an educational building for Bath Schools of Art and Design after 2016, by Elyse Howell-Price and Allan Green of Grimshaw Architects[390].

The original design brief – which reads almost like a manifesto – was quoted in academic publications at the time of completion of the building, for the philosophy of the building was remarkable: a factory that easily adapted to changing times and needs[391]. The factory had a free floor plan that could accommodate the large machinery required for furniture production. The façade, built up from two sandwich panels of glass-fibre reinforced polyester (GRP) with cores of polyurethane (fig. 31), could be replaced by

388 Ellen Peirson, 'Bath Schools of Art and Design.', *Architectural Review*, no. 1483 (July 2021): 37, 151650168; Grimshaw Architects, 'Herman Miller Factory: Architectural Systems', accessed 8 July 2025, https://grimshaw.global/projects/industrial-design/herman-miller-factory-architectural-systems/.

389 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 89; Richard Waite, 'Farrell and Grimshaw's Bath Factory Listed', The Architects' Journal, 2 September 2013, accessed 8 July 2025, https://www.architectsjournal.co.uk/archive/farrell-and-grimshaws-bath-factory-listed.

390 Peirson, 'Bath Schools of Art and Design.', 42.

391 'Miller on Avon', *Domus* 576 (November 1977): 20.

fig. 31. *A section through a Herman Miller Factory facade panel, showing the two GRP sandwich panels that together form the facade. Photo R. Loader.*

unskilled workers. The panels were produced by Artech Plastics[392].

These panels were hung in aluminium frames with neoprene gaskets that are prominently visible (fig. 33). The windows panes had the same thickness as the sandwich panels at the edges and therefore both fitted into the same profile, which made them interchangeable. The integrated insulation, the cavity, but also the roof insulation and the low wall-to-floor ratio were at the time of completion seen as highly energy efficient[393].

An analysis on the state of the façade was written by Montressor Partnership[394]. The panels experienced some delamination at the edges. Also some crazing was visible, through a later applied paint layer. Furthermore, biological decay was present. The fixings were corroded and in some cases missing.

The architects designed an interesting restoration, which also included an energy retrofit. The insulation in the roof parapet panel, which never had a sandwich structure like the other panels, has been replaced completely (fig. 34).

The flexibility in the floorplan ensured that the building could accommodate a rather different function than a factory: a school of art. The renowned energy efficiency, however, was surpassed by the building norms of the current era.

Several elements were replaced, for instance the new heat-cured silicone gaskets, instead of the existing neoprenes[395]. Roughly half of the screws that fixed the

392 Brookes, *Claddings of Buildings*, 47.

393 'Miller on Avon', 20.

394 Montresor Partnership, 'Site Investigation of Existing External Façade Cladding: 20th + 21st March 2017', 26 April 2017, 4–5, 17/02033/FUL, Bath & North East Summerset Council archives.

395 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 90.

pressure plate to the aluminium frame and the aluminium frame to the RHS frames were corroded and had to be replaced[396].

The panels itself were largely intact and only fifty of them had to be replaced[397]. In the past, the panels had been painted over twice or even three times, with a colour that did not entirely match the original colour[398]. The other panels showed some edge delamination and crazing through or behind the remedial paint. Furthermore, algae were present on the panels.

The panels were removed from the structure and sanded, cleaned and spray painted on site. The chosen paint was Selemix 7-532 polyurethane paint[399]. The architects deliberately choose to not use a high-gloss paint, even though the original paint was, as this would highlight imperfections of the substrate[400].

To address the energy efficiency norms, new insulation was added behind the panels. This new insulation was mainly covered with wooden sheathing were student's work could be displayed on. As with the Commerzbank, the existing frames, that in this case hold both the panels and the windows, were too narrow for insulated glazing. The architects of Herman Miller opted for a different approach than the designers of the Commerzbank, who replaced both the windows and the frames. On the windows of the factory was added a cavity and two panes of glass (see fig. 33)[401]. Attention was paid to the appearance of the glass, as the 'middle' panel was heat strengthened, Planibel bronze glass.

396 Montresor Partnership, 'Site Investigation of Existing External Façade Cladding: 20th + 21st March 2017', 4.

397 Loader, 'Deterioration, Harm and Conservation of Building Plastics Heritage', 90.

398 Ibid.

399 Ibid.

400 Ibid.

401 Structura UK, 'Existing Façade Glazing', 26 April 2017, 5, 19/02292/COND, Bath & North East Summerset Council archives, https://app.bathnes.gov.uk/webforms/planning/details.html?refval=17%2F02033%2FFUL#details.

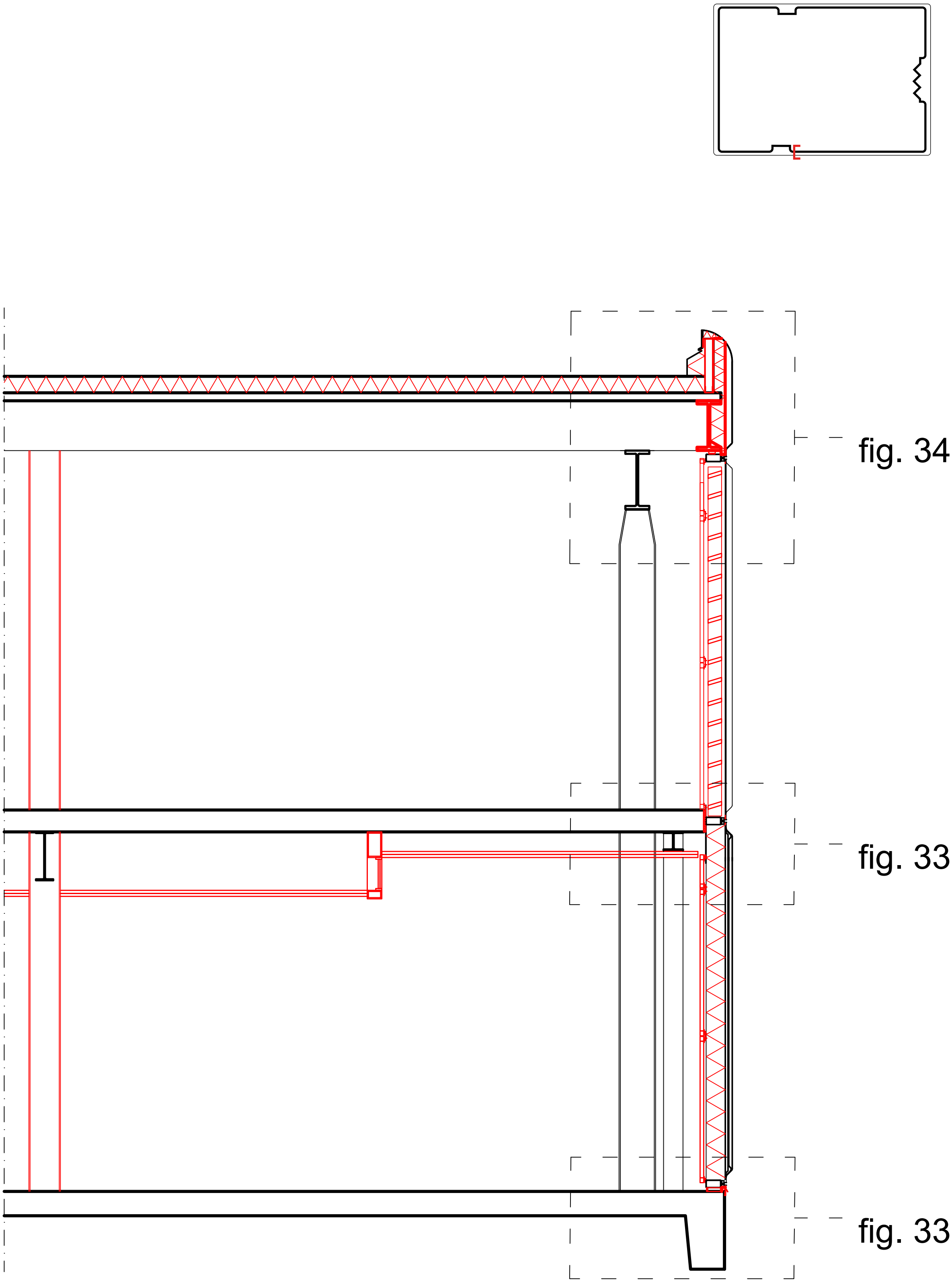

fig. 32. *Section of Herman Miller Factory in Bath. Scale 1:50. After Grimshaw Architects, elaborated by the author.*

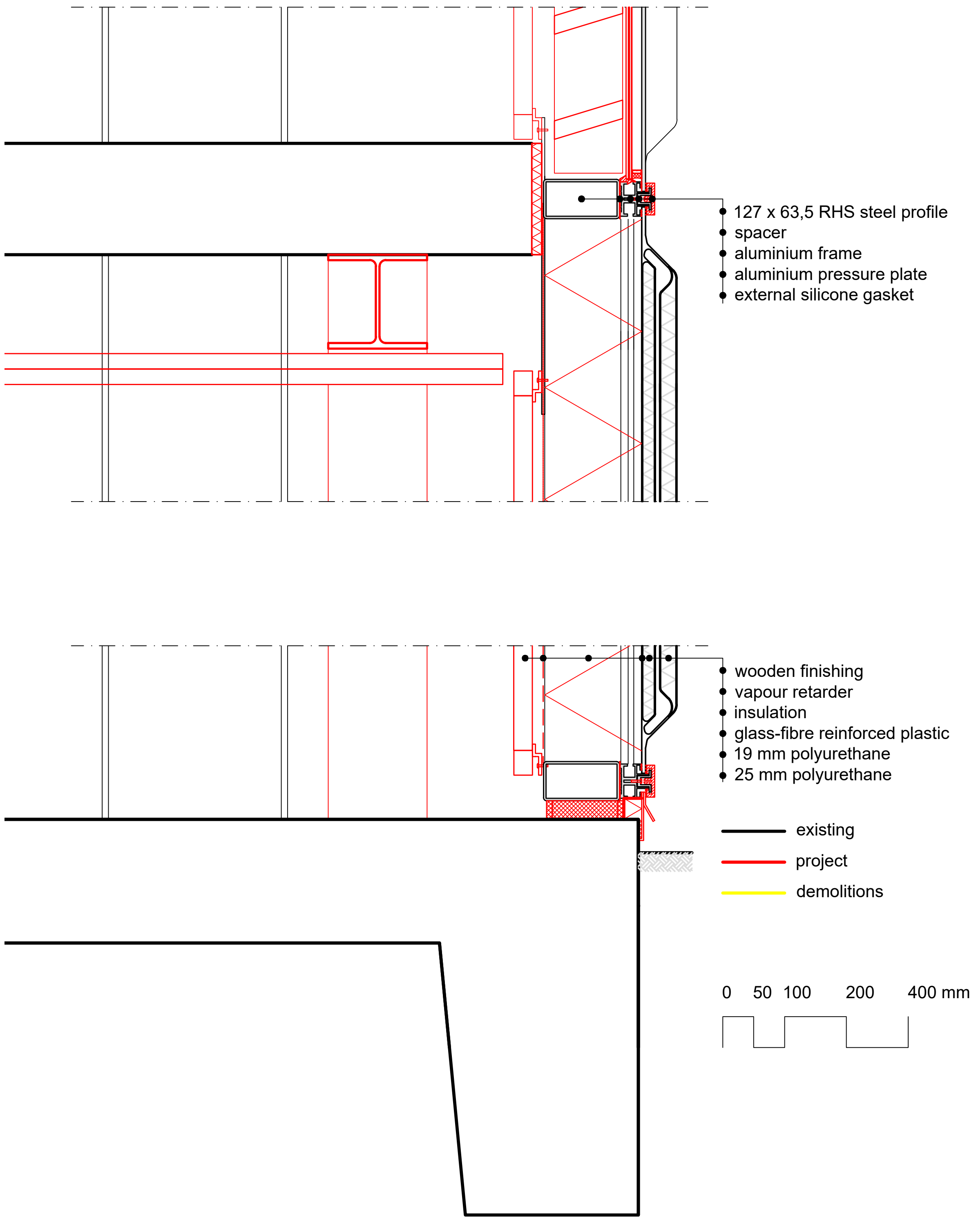

fig. 33. Section at the bottom and the middle of the facade of the Herman Miller Factory in Bath. Scale 1:10. After Grimshaw Architects and Montresor Partnership, elaborated by the author. Key plan adapted from Peirson 2021.

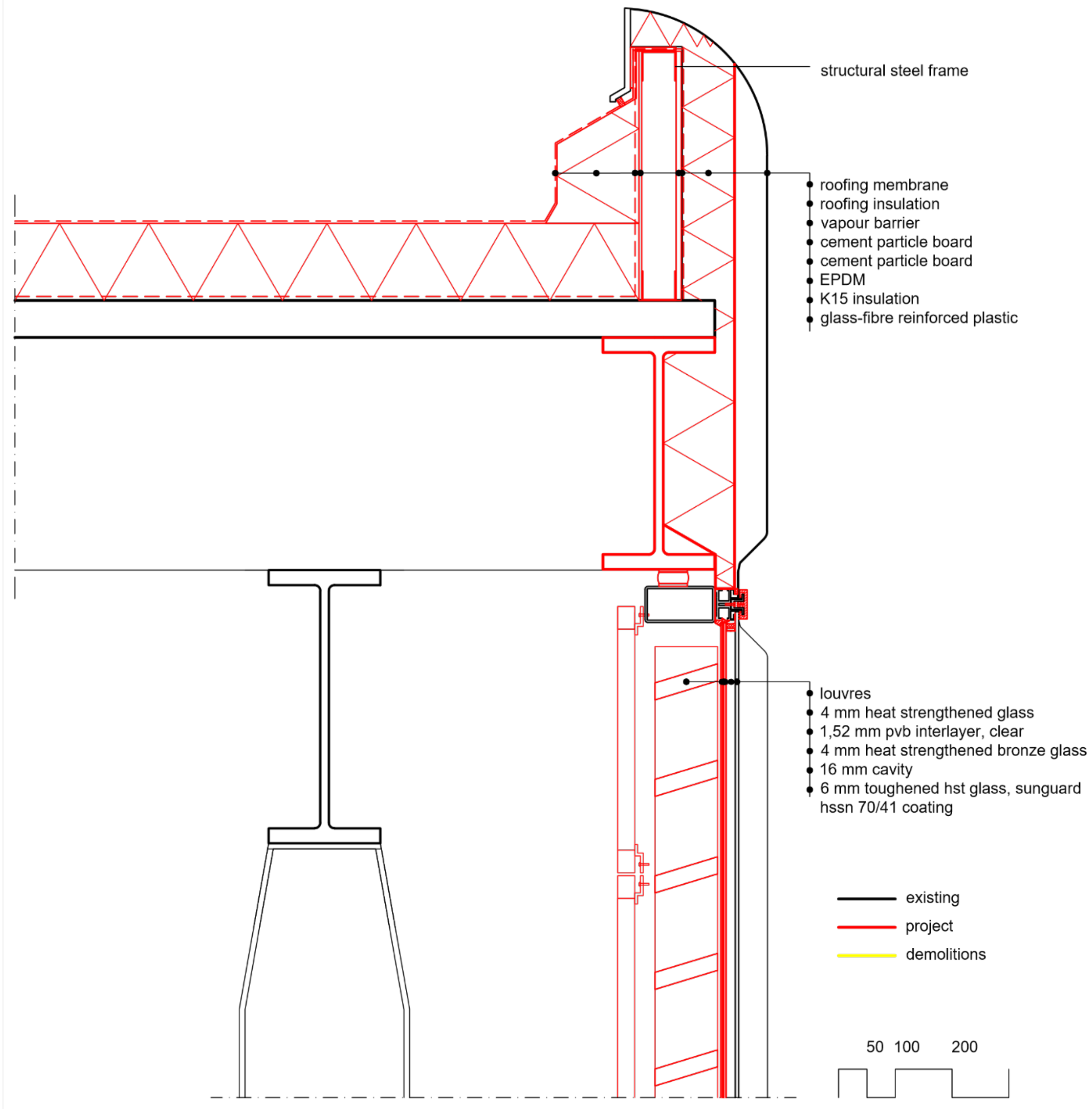

fig. 34. Section at the roof of the Herman Miller Factory in Bath. Scale 1:10. After Grimshaw Architects and Montresor Partnership, elaborated by the author. Key plan adapted from Peirson 2021.

fig. 35. The Futuro in Munich with its remarkable stairs. Photo Peter Neusser, München Tourismus.

3.4. Futuro

The Futuro, as mentioned in the first chapter, was an experimental GRP building by Matti Suuronen (1968)[402]. Even though the building was designed to be mass-produced, only 100 units were built, of which a little more than 60 still exist to this day[403]. These "flying saucers" are in possession of admirers and museums worldwide. The prototype of the Futuro, number 000, has a remarkable provenance, being mostly in private collections before being on loan for an exhibition in Vienna, after which the owner never reclaimed the building[404]. After this, the 000 has been exhibited on several location before being in the possession of the Centraal Museum in Utrecht until 2007 and it is currently located in Museum Boijmans van Beuningen in Rotterdam[405]. This Futuro, the prototype, was restored between 2010 and 2011[406]. The building is currently disassembled in the depot of the museum, inaccessible to the public.

Another Futuro is located in Munich (fig. 35), in die Neue Sammlung of

402 Voigt, 'The Futuro', 40.

403 Ibid., 41–42.

404 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 24; Ranti Tjan, 'The Return of the Prototype = Protoyypin Paluu', in *Futuro : Tomorrow's House from Yesterday = Tulevaisuuden Talo Menneisyydestä*, ed. Marko Home and Mika Taanila (Desura, 2002), 50.

405 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 60–61; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78.

406 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78.

the Pinakothek der Moderne, where it was restored between 2016 and 2017[407]. This unit is permanently exhibited in front of the museum.

These two units are the European variant, which was produced by the Finnish company Polykem Oy[408]. The Futuro was also produced in the United States, by the Futuro Corp. under license[409]. The European Futuros consist of sixteen pieces that are bolted together, the American variant of two – an upper and a lower shell[410]. The support ring the Finnish edition is placed on, does not exist in the American variant, which has a support that is hidden inside the shells[411]. The Finnish Futuro has four extra lower windows, which can be used as escape routes, whereas the American variant only has two[412]. This is because the floor in the American Futuro is slightly raised (19 cm) with respect to the Finnish, to create a larger floor area[413]. The door in the American edition is located directly under a window, whereas the European has a door that is below the middle of two windows[414]. The American edition has a steel framework beneath the floor[415].

The Futuros were made using the hand lay-up or laminating technique, as described in chapter 2.2.1. [416]. The Futuro is then assembled on-site. The connections are bolted (M10)[417]. The Futuro could be transported by helicopter, as the Swedish army did[418]. Pictures of the transport by helicopter were used in advertising, and they still appeal to the imagination, but this way of transport is rather expensive and impractical and was therefore not common practice[419].

The restoration of these two Futuros is documented in several papers and in an article that compares the interventions on these and two other Futuros[420]. Furthermore, the standard work *Futuro: Tomorrow's House from Yesterday* and an online archive (thefuturohouse.com) provide access to pictures,

407 Ibid.; Voigt, 'The Futuro', 41.

408 Milford Wayne Donaldson, 'The Donaldson Futuro: Rescue, Relocation, and Restoration Challenges', *Docomomo Journal*, no. 66 (December 2022): 51, https://doi.org/10.52200/docomomo.66.06; Sánchez Samos, 'Arquitectura Sin Lugar', 106; Eugenia Stamatopoulou et al., 'The Futuro House in Limni, Corfu: A Living Space', *Docomomo Journal*, no. 66 (December 2022): 68, https://doi.org/10.52200/docomomo.66.08; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78;

409 Donaldson, 'The Donaldson Futuro', 51; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78; Voigt, 'The Futuro', 43.

410 Donaldson, 'The Donaldson Futuro', 51.

411 Ibid., 51; Voigt, 'The Futuro', 46.

412 Donaldson, 'The Donaldson Futuro', 51; Voigt, 'The Futuro', 46.

413 Voigt, 'The Futuro', 46–47.

414 Ibid., 46.

415 Ibid.

416 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 63; Stamatopoulou et al., 'The Futuro House in Limni', 68; Voigt, 'The Futuro', 43.

417 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 63; Stamatopoulou et al., 'The Futuro House in Limni', 68; Voigt, 'The Futuro', 45.

418 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 62.

419 Voigt, 'The Futuro', 43.

420 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype'; Tyurkay and Pottgiesser, 'From Deterioration to Revival'; Voigt, 'The Futuro'.

drawings and other archive material[421]. The comparison between the two Futuros in the museum collections and between the Futuros and the Herman Miller factory in Bath illustrates how the different needs and structures influenced the restoration process of these GRP buildings.

3.4.1. Restoration of Futuro 000 (Rotterdam)

The 000 was restored under the lead of Lydia Beerkens, with the help of Samy Supply, Nikki van Basten and Poly Products[422]. The restoration report, written by Lydia Beerkens, is located in the archives of the museum[423].

This Futuro has a light blue gel coat, which is original[424]. The shell suffered from mechanical damage[425]. It was assembled and disassembled over ten times[426]. Van Basten, at the time a student at the University of Amsterdam Master's degree in Conservation and Restoration, took part in the restoration process of the prototype and documented this for an academic paper, which is archived in the library of the museum. On the assembling of the Futuro for the exhibition in 2011, she writes: "During the participation in the assembling in May this year [2011], I learned that the *Futuro* had to undergo a lot of stress, because several parts could only be put in position with 'violence'."[427] The sixteen parts deflected permanently under their own weight as they were stored individually[428].

Furthermore, they displayed fractures and delamination[429]. Some fractures could also be the result of human action, during the transport and handling[430]. Apart from these fractures, several drilling holes are present, some of which are filled, although not all successfully colour-matched[431].

The outer skin also displays little cavities, which are likely the result trapped

421 Marko Home and Mika Taanila, eds, *Futuro : Tomorrow's House from Yesterday = Tulevaisuuden Talo Menneisyydestä* (Desura, 2002).

422 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78.

423 Lydia Beerkens, 'De Conservering van CASA FUTURO (prototype) 1968 van Matti Suuronen (Museum Boijmans van Beuningen). EINDRAPPORT (2011) van de uitgevoerde conservering in 2010.', 25 March 2011, Museum Boijmans van Beuningen.

424 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

425 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 61.

426 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78.

427 Nikki Van Basten, 'Case Study', 2011, 13, 2013/0054, Library Museum Boijmans Van Beuningen. Translation MT, italics NvB.

428 Beerkens, 'Eindrapport van de conservering van Futuro-house', 3.

429 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 61; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79; Van Basten, 'Futuro', 10.

430 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

431 Van Basten, 'Futuro', 10.

air during the production of the shells[432].

Also weathering, UV-radiation and freeze-thaw cycles caused deterioration to the structure, like chalking of the gelcoat, fading of the colour and micro-cracks[433]. This deterioration – fractures and microcracks – allowed water to penetrate the polyester shells, causing mould and algae growth[434].

The outer skin of the 000 shows differences in colour and even some brush strokes are still visible[435]. The fact that unexposed parts, like for instance where the ring supports the shells, are not discoloured, strengthens the hypothesis that the discolouration is because of UV radiation[436]. Other parts that are not discoloured are for instance the stairs/entrance door, about which Beerkens suggests that they might have been replaced before the Futuro entered a museum collection[437].

The inner skin was still in good condition, but some drilling holes were present[438]. Also the internal gutters were brittle[439]. The PMMA windows were still original and in good condition[440]. The gaskets were still present, although several lost parts had been filled up with a different colour of rubber[441]. There are however holes in the outer skin, just above the windows that suggest an original presence of a little edge to protect the window from rain, which is also visible on pictures in *Tomorrow's House from Yesterday*[442].

Determining the future use and way of exhibiting was an essential step in developing a restoration intervention. A permanent outdoor exhibition would mean less assembling and disassembling, but also more suffering from environmentally caused deterioration[443]. An optional strategy would be to regularly recoat the Futuro with a sacrificial coating, which would imply extra costs, or with an irreversible coating, like a two-component polyurethane lacquer[444]. An outdoor exhibition would be

432 Beerkens, 'Eindrapport van de conservering van Futuro-house', 3.

433 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 61; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

434 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 61.

435 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79; Van Basten, 'Futuro', 9.

436 Beerkens, 'Eindrapport van de conservering van Futuro-house', 3.

437 Ibid.

438 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 61; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79; Van Basten, 'Futuro', 10.

439 Beerkens, 'Eindrapport van de conservering van Futuro-house', 3.

440 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

441 Beerkens, 'Eindrapport van de conservering van Futuro-house', 6.

442 Ibid., 7; Home and Taanila, *Tomorrow's House from Yesterday*, 40.

443 Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 62.

444 Ibid.

a good representation of the original intended use.

An indoor exhibition would imply more assembling and disassembling, as the museum has no space to permanently exhibit the structure.[445] On the other hand, the restoration interventions could be less impactful, as the 000 would not be exposed to the elements and vandalism[446]. In this way, the marks the time left on the Futuro also remained visible[447].

Because the Rotterdam Futuro is the first Futuro produced, it was decided to opt for an indoor exhibition, as this would make sure the Futuro could stay in a state closer to the original[448].

The restoration of the 000 included the cleaning and polishing of the gelcoat, with a very fine abrasive[449]. Larger lacunes were filled with resin and fibreglass, and smaller holes with only resin[450].

The steps were in a weak condition. They were separated from the door, the insulation was removed and they were reinforced with plywood and polyester[451]. A honey wax was used to repel dirt[452].

The core material, PUR, showed detachment, but it was chosen to not intervene[453]. The insulation material does not have a biophysical function anymore, hence conservation of the existing fabric without restoring was sufficient.

The interior skin was cleaned and polished, larger holes were filled, smaller holes were left untreated[454]. At one rib, glass fibre mat reinforcement was placed[455]. A purple latex paint was used to paint the interior, in order to create a coherent image[456].

The PMMA windows are original and were cleaned, so were the rubber gaskets, of which some had to be replaced because they were lost[457]. It was decided to not replace the window edges, that were probably present in the past.

The restoration approach of Futuro 000 showed a clear philosophy that resulted in minimal

445 Ibid.

446 Ibid.; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 81.

447 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 81.

448 Beerkens, 'Eindrapport van de conservering van Futuro-house', 2; Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 62.

449 Beerkens, 'Eindrapport van de conservering van Futuro-house', 5; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

450 Beerkens, 'Eindrapport van de conservering van Futuro-house', 7; Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 64; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

451 Beerkens, 'Eindrapport van de conservering van Futuro-house', 9; Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 65; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

452 Beerkens, 'Eindrapport van de conservering van Futuro-house', 5.

453 Ibid., 3.

454 Ibid., 9.

455 Ibid., 10.

456 Ibid., 11.

457 Ibid., 5; Beerkens, 'Matti Suuronen's 'Futuro'-Prototype', 62; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 79.

interventions – replacement of lost parts, cleaning and filling up holes – but also meant a loss of function. The current use is not close to the use once intended and at the time of writing, the Futuro has been in the depot for thirteen years. This is a common fate for many museum objects, but usually not for architectural works.

3.4.2. Restoration of the Munich Futuro

The Munich Futuro, in a museum collection as well, had been restored using a different approach. The building is currently exhibited outdoors in Munich. A first intervention, between 2010 and 2013, was carried out by the Charles Wilp Museum, where it was exhibited at the time[458]. A second intervention, in the years 2016 and 2017, was performed by Tim Bechtold, Pamela Voigt and SKZ: Das Kunststoffzentrum[459].

The Munich-Futuro suffered from similar conservation issues. Because was and is exhibited outdoors, biological decay is present[460]. Temperature fluctuations cause local cracks, which endanger the structural integrity[461]. Water accumulated inside the Futuro, also because there was space between the upper elements[462]. The surface was discoloured, cracked and showed some detachment of layers, like the Rotterdam Futuro[463]. The wooden flooring elements were damaged by moisture[464]. Causes for the deterioration were atmospheric and ageing, but also vandalism[465].

Conservation interventions were the replacement of the GRP where necessary, but also partial replacement of the PUR core[466]. The coatings were removed down to the gelcoat and the entire surface was repainted (fig. 36)[467]. The same interventions were performed on the inner skin of the panels. New windows, skylights as well as the gaskets were installed, because the original windows

458 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 78.

459 Ibid.

460 Francesca Cappitelli et al., 'Biodeterioration of Modern Materials in Contemporary Collections: Can Biotechnology Help?', *Trends in Biotechnology* 24, no. 8 (2006): 351, https://doi.org/10.1016/j.tibtech.2006.06.001.

461 Stamatopoulou et al., 'The Futuro House in Limni', 72.

462 BAKU, 'Instandsetzung Des Futuro Vlotho/Witten', BAKU – Bauen Mit Kunststoffen, accessed 20 November 2025, https://kunststoffbauten.de/bauen/futuro/.

463 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 80.

464 BAKU, 'Instandsetzung Des Futuro Vlotho/Witten'.

465 Stamatopoulou et al., 'The Futuro House in Limni', 72; Tyurkay and Pottgiesser, 'From Deterioration to Revival', 80.

466 Tyurkay and Pottgiesser, 'From Deterioration to Revival', 80.

467 Ibid.

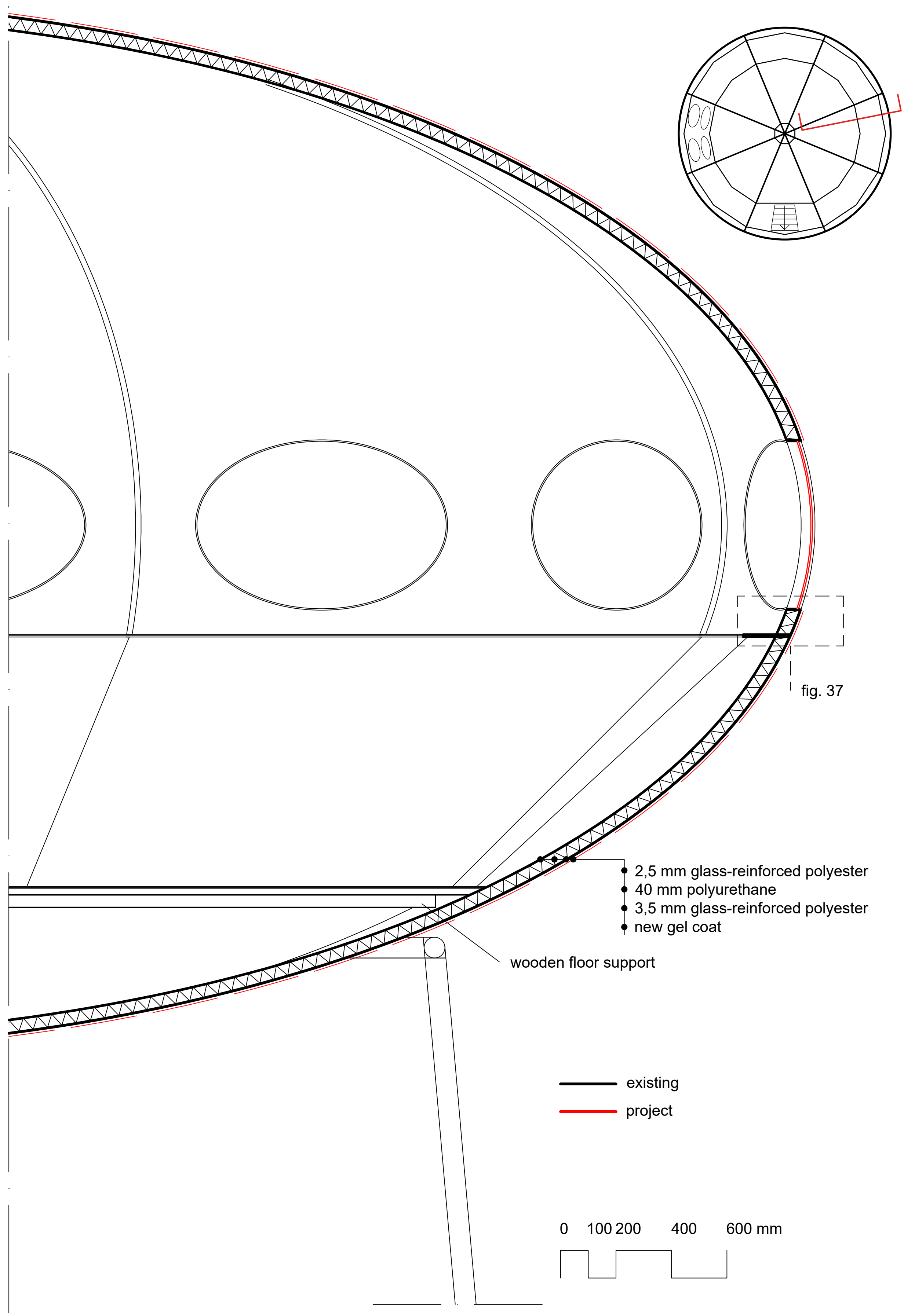

fig. 36. Section of the restoration intervention of the Munich Futuro. Scale 1:20. Elaboration by the author after BAKU, Beerkens 2011, Van Basten 2011 and Voigt 2022.

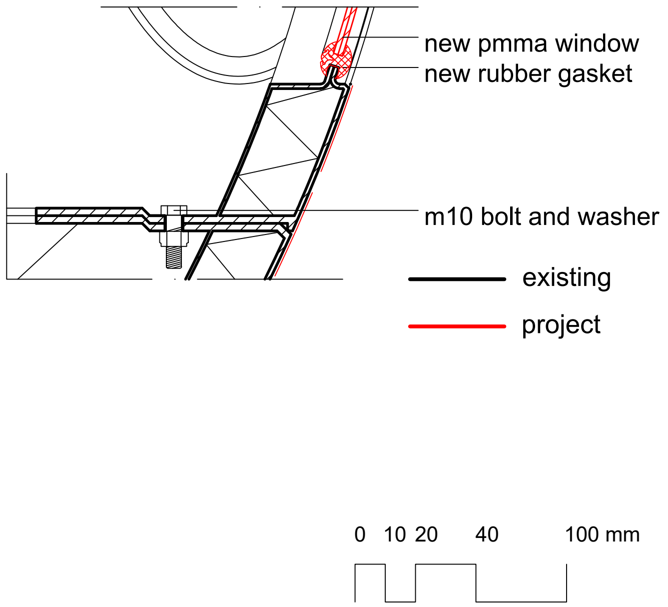

fig. 37. Detail of the restoration intervention of the Munich Futuro. Scale 1:5. Elaboration by the author after BAKU, Beerkens 2011, Van Basten 2011 and Voigt 2022.

were replaced by flat windows during the 2010-2013 intervention (fig. 37)[468].

The intervention of the Munich Futuro is more invasive than the restoration of the 000. Both the Futuros had to undergo small repairs of the GRP. The lacunes in the PUR of the Rotterdma Futuro are not filled up, as opposed to the Munich Futuro. The Rotterdam Futuro will be exhibited indoors; for the indoor climate and the risk of condensation, a fully intact insulation layer is not necessary. The replacement of elements like the gaskets and the repainting of the outer surface of the Munich Futuro were both a necessity when displaying the Futuro outdoors, as a choice for showing the original appearance of the design. It is in better condition than the prototype and will be seen much more by the audience.

3.5. Comparison

The four studied project are different in several ways. Apart from obvious differences like location and architect, the comparison of materials used, the building age, the level of protection under heritage law and the eventual proposed new function of the building allow

468 Ibid.

for an interesting comparison of the different approaches to the restoration.

3.5.1. Skin materials

The aluminium skin case studies, the Commerzbank and the Briefzentrum, both had signs of exposure to the elements. Structurally, the panels on both the buildings were intact. The Commerzbank building was protected against corrosion by anodising the aluminium and the Briefzentrum had a powder-coated surface to prevent oxidation.

The panels of both buildings were abrasively cleaned. The abrasive cleaning of anodised panels, which was for instance performed at the Commerzbank, is contested in academic literature[469]. It is a last resort to maintain the building. The abrasive cleaning of the panels of the Briefzentrum, on the other hand, was performed with the *intention* to remove the powder-coating. The loss of original fabric was justified by the promise of a building with an appearance similar to the original .

The buildings in GRP, the Herman Miller factory in Bath and Futuros in Rotterdam and Munich, all suffered from human-caused damage, like drill holes. Also biological decay was present in both buildings. The delamination at the edges of the panels, present in Bath, did not occur in Rotterdam or Munich. The severe deformation in Rotterdam was unique.

The cleaning process of the Munich Futuro and the furniture factory was comparable. The panels of both the buildings were sanded and recoated. The Rotterdam Futuro was different, as it was only cleaned. A protection layer was not necessary because the structure will be exhibited inside the museum.

Both the panels from the Herman Miller factory and the Futuros in Munich and Rotterdam were repaired.

469 Cf. Godfraind et al., *Metals*, 331; Kelly, 'Aluminum', 51.

The Futuros both have all their original panels, whereas fifty panels of Herman Miller had to be replaced.

3.5.2. Insulation

The buildings with an aluminium skin used different insulation materials. The insulation of the Commerzbank was fully replaced, for reasons of fire safety. The material used – 45 mm phenolic resin impregnated paper honeycomb filled with synthetic resin foam – was not incombustible, and therefore replaced by mineral wool (45 mm). More insulation, namely 82 mm of mineral wool, was added in the cavity.

At the Briefzentrum, the insulation, which had a thickness 100 mm, was left untouched. The mineral wool was not tested and had not reached its expected lifetime. For fire-safety reasons, a fire-retarding interruption was placed.

The GRP buildings – the Futuros and the furniture factory – used a PUR foam insulation. The insulation of the Futuros has a thickness of roughly 40 mm, whereas the insulation of the Herman Miller is split into two portions, with a thickness of 19 and 25 mm. The overall insulation value should therefore be comparable.

The lacunes in the insulation in the Munich Futuro were filled up. Articles on the restoration of the prototype do not mention lacunes, but as the buildings have the same structure and both have been displayed outdoors over the course of the years, it is thinkable that these lacunes are also present in the 000. It was however not mentioned or researched, as there was less relevance because the Futuro will be displayed indoors.

At the restoration of the Herman Miller Factory, 150 mm of extra insulation was added. The original insulation remained in place.

3.5.3. Windows and gaskets

The Commerzbank and the Herman Miller factory both had single-pane glass windows. The Briefzentrum already double-pane windows, as it was built between 1981 and 1985, as opposed to 1959-1962 for the Commerzbank and 1976 for the furniture factory. The Futuro, of which the first was built in 1968, had PMMA windows.

The windows of the Briefzentrum were not replaced, nor altered. The PMMA windows of the Rotterdam Futuro were still intact and left untouched. The windows of the Munich Futuro were already replaced at the previous intervention at the beginning of last decade, but were changed again during the last restoration in 2016-2017, because the replacement windows were flat instead of double curved.

The original window frames of the Commerzbank did not leave enough space for double-glazed windows. It was therefore decided to replace both the windows and the window frames. The opening mechanism is also different, to allow more efficient ventilation . Instead of pivot windows, the windows now open in horizontal direction.

Nicholas Grimshaw Architects, who designed both the original Herman Miller factory as the restoration, opted for a different approach. Also in this case the window frames were to narrow to accommodate double-glazed windows. The architects choose to attach a second pane to the original pane. In this way, the original window frames, which were quite characteristic of the building, remained in place.

Striking is that the neoprene gaskets of both the Herman Miller factory and the Commerzbank had to be replaced due to ageing of the material. The rubber gaskets of the Futuros only had to be replaced in case of loss of material. The gaskets of the

Briefzentrum remained as they were.

3.5.4. Considerations for an intervention strategy

For the choice of intervention strategy, several factors played a role. Apart from technological possibilities, the grade of protection at the time of the intervention, and the proposed new function were of interest for the restoration design.

The Briefzentrum, for instance, was treated quite conservatively. The structure and insulation remained the same. The intervention on the outer skin, on the other hand, was quite invasive. The building was protected by law only after the intervention, which probably made the irreversible abrasive cleaning of the original powder-coating possible. The fact that the function – a mail sorting centre – remained unchanged and did not require an ambient temperature, added to the fact that this relatively young building (1985) did not need extra insulation to comply with modern standards. The building was listed a cantonal monument some time after the restoration was completed.

The Futuros – both in Rotterdam and Munich – were also treated quite conservatively, which seems suitable for two objects that are part of museum collections. The strategy for the 000, in Rotterdam, leaned more towards conservation than to restoration, as no effort was taken to improve the building, only to stabilise the existing condition. The museum has no indoor space to permanently exhibit the Futuro, but outside exhibition is not an option anymore due to the chosen restoration approach. An important disadvantage hereof, is that the structure has to be assembled and disassembled, which is limiting the life span. The Munich Futuro was treated more invasively, with repairs of the PUR insulation core and a total replacement of the outer layers of the object, but it is exhibited outdoors, in a way that is quite close to the original meaning of the building.

The Commerzbank was already protected under heritage law when the interventions were performed. As mentioned before, more or less every element between the outer skin of the panel and the concrete structure was replaced. The loss of original fabric was in this case justified by the fact that the fire safety and the lack of insulation did not allow the building to be used. By replacing the insulation and the mounting system, the building could be commercialised[470]. The hotel function, or any other possible commercial function, is in this case a requisite for the continued maintenance of the building.

3.6. Findings

The buildings analysed differ greatly in technology used for preservation and restoration. The structures that were under the strongest protection were treated the most conservatively. Other case studies were protected by law only after the completion of the intervention.

Even though the increased interest in insulation in society after the oil crisis of 1973 was favourable for a system that is by definition insulated like the sandwich panel, many sandwich panels do not comply with current energy norms. Sometimes insulation is added in the cavity between the sandwich panels and the structure, but the original insulation can also be replaced. In the analysed cases where no extra insulation was added, it regarded a relatively recent building or a structure in a museum collection.

The changing energy norms also had implications for the windows which were in most cases integrated in the panels or in the same framework the panels were hung in. The restoration architects opted for different solutions which differed in

470 Grom and Putz, 'Renovating Modern Heritage', 64.

degree of invasiveness. In the case of the Commerzbank, the entire window frame had to be replaced to accommodate safe and energy-efficient windows. The detailing of the Herman Miller factory windows can be regarded as innovative, as it is reversible and retains as much original fabric as possible.

Conclusions

Half of the buildings in the European Union was built between the end of the Second World War and the fall of the Berlin Wall. These structures form a large part of the world we live in and a great deal of the surroundings many Europeans grew up in. At the same time, buildings from this era are not (yet) protected by law. In many countries and regions building age is a hard requirement for a building to be enlisted as a monument, which causes the buildings from this era to be excluded.

These structures, especially the older ones, have now reached the end of their technical lifespan, or will do so in a few years. The buildings concerned often have components that are smaller and more vulnerable than buildings from earlier eras have. Instead of constructing for eternity, buildings are designed to have a limited technical lifespan: so-called ephemeral architecture. The need for research on the preservation and restoration of these components is eminent.

The building element central in this work, the sandwich panel, is a fairly vulnerable building component. Built-up in often thin layers, with small components and complex attachment to the structure, it is not surprising that conservation problems arise in buildings with sandwich panels.

The history of a construction system gives insight in the unicity of an individual building. It provides the structure with context, which is essential for developing an intervention strategy. Furthermore, the history of a construction system shines light on how architects in the past used this for their architectural expression.

Sandwich panels were developed on both sides of the Atlantic Ocean, just a few years before the Second World War. The French blacksmith and engineer Jean Prouvé developed non-load-bearing steel panels with an insulating core, whereas Frank Lloyd Wright and his student Alden B. Dow in the United States used panels that were load-bearing.

The sandwich panel was further developed after the WW II. Several experimental plastic houses were developed in Europe and the United States. Some of them used sandwich panels, like Monsanto's House of the Future, that was a popular Disneyland Anaheim attraction between 1957 and 1967. The oil crisis of 1973 and several fires made sure that plastic homes would not become the houses of the future. The sandwich panel, however, remained.

Towards the last decades of the previous century, the sandwich panel was used more and more. Not often in housing, but in industrial buildings, the construction system was very popular. Architects used the system to give their creations an industrial appearance. Banks and museums, building types with a strict morphology, were designed radically different by architects like Renzo Piano and Richard Rogers.

Profound knowledge of the materials employed in the sandwich panels is vital for professionals who work with these systems. The main material groups are metals, plastics, asbestos and precast concrete.

Metal sandwich panels, most often constructed in aluminium or steel, are quite durable. Oxidation is for these materials the biggest threat. Several ways exist to protect steel from corrosion, like using stainless steel, galvanising steel or coating it. Aluminium is often anodised, which is the process of controlled oxidisation to form a protective patina. When these protective layers are broken, aluminium and steel sandwich panels can oxidate, which can be a threat for their structural integrity and their appearance.

Metal sandwich panels can be cleaned using mild detergents. Abrasive cleaning is possible, but should be avoided because chances are that the protective patina is broken, which would form a risk for oxidation.

Plastics, like PMMA, glass-fibre reinforced polyester, PVC and high-pressure laminate often don't have a protective layer, because their smoothness makes them less vulnerable to decay like biological colonisation. UV-radiation is a serious risk factor, on the other hand. It causes yellowing and cracks. Biological agents for instance can then deteriorate the material.

The material can be cleaned and also small patch repairs are often possible. The process of yellowing, on the contrary, is irreversible and stabilisation is the only option.

A material that raises different ethical dilemmas in the design of restoration is asbestos. Apart from technological possibilities, the proposed use of a building and the desire to preserve a building for future generations, a serious health risk is to be considered. It is a form of 'dissonant' or 'difficult' heritage, because it is undeniably connected to the suffering of the asbestos workers and their relatives. They form a heritage community that is atypical: rather than preserving the asbestos legacy, some of them might wish to erase the memory of the asbestos industry.

The technological possibilities to seal asbestos exist. Also the techniques to create replicas that can replace asbestos products are well-known. It is an ethical, and sometimes legal consideration how to design an intervention on sandwich panels that contain asbestos.

The only material that is used in vertically load-bearing sandwich panels is precast concrete. The panels can be reinforced using glass-fibres or steel. Steel reinforcement makes the panels susceptible to corrosion. Glass-fibre reinforcement looses tensile strength over the course of the years. The cement matrix is vulnerable for carbonatation, alkali-silica reaction or sulphate attack.

Corrosion can be treated using a variety of solutions. Also carbonatation, alkali-silica reaction or sulphate attack can often be stopped. In severe cases replacement is inevitable.

The skin materials of the buildings analysed all had some form of decay. The way the decay was treated differed greatly, from completely removing the protective layer to retaining it as much as possible. This is due to the differences in protection level and different objectives of a restoration intervention.

Often insulation had to be added to the sandwich panels. Sometimes, existing insulation was replaced, for instance for fire safety reasons. In other cases, existing insulation already fulfilled the energy requirements, or the wish to keep the building as it was prevailed over the user comfort.

The windows, which were in most cases integrated in the panels, were in some cases retained, but in other cases innovative solutions were invented to create user comfort. The windows of the Herman Miller have a second pane added to them. This is an interesting intervention which allowed the original frames to be retained.

The broadness of the subject of this writing has its implications for the subjects treated. Further research is part of a healthy academic and professional restoration field. Academic research on restorations of sandwich panels was and is scarce. Several restorations of sandwich panels have been executed without a publication in professional or academic literature. Therefore, the recommendation is to further research restorations of building with sandwich panels.

Furthermore, not all materials used in sandwich panels have been given the same amount of attention in the research. Insulation materials, for instance, are outside of the scope of this work. They do, however form an integral part of the panels and often play a key role in restorations or transformations, as energy requirements are increasingly important.

In general, it can be concluded that sandwich panels form an integral part of the architectural history. From their development in the 1930s to these days, they are used as a tool of architectural expression – often to design a building with a high-tech appearance. Knowledge on their restoration is therefore vital for the preservation of a large part of the built legacy.

The great variety of materials used makes it difficult to identify key sources of deterioration. Decay is often treatable with the right techniques. Deterioration can then be stabilised. In some cases, replacement of fabric is necessary to prevent further loss.

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