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Circular Steel – Technologies and Processes for the Reuse of Dismantled Steel Profiles in uptownBasel

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Abstract. The former industrial site of uptownBasel in Arlesheim, Switzerland, has great potential for local reuse of steel profiles, as disassembly, processing, and storage can be handled within the same site. The direct reuse of steel is significant because it contributes to a reduction in greenhouse gas emissions, especially when transportation and processing are minimized. This study addresses how the dismantled steel profiles in uptownBasel can be made accessible for future use, considering both physical and digital accessibility. Based on stakeholder consultations and literature research, this study examines which technologies and processes are suitable for the reuse of dismantled steel profiles in uptownBasel. It analyzes and compares existing Track-and-Trace as well as data storage technologies. Data requirements for the reuse of steel are examined by regarding constant and variable information and structuring it according to its data type (numeric, alphanumeric, vector, or image-based) specific to the uptownBasel use case. Furthermore, an analysis of storage types reveals important distinctions: Whether single or multiple storage units are needed, whether the storage is intended to be long-term or short-term, and whether materials should be stored sorted or unsorted. Finally, this study provides an outlook on how the process and the tasks of those involved in the project change when steel profiles are labelled and their information is made digitally accessible.

1. Introduction

The consequences of climate change and increasing resource scarcity have heightened awareness of how load-bearing structures contribute to the environmental impact of building construction, particularly those made of steel (1). Compared to other building components, load-bearing structures have the longest service life – up to 300 years – and the largest CO_2 footprint, accounting for 30% of a building's overall impact (2,3). After aluminum, steel is the structural material with the highest greenhouse gas potential during production (4). However, steel's high strength requires less material, smaller foundations, and fewer material transports than comparable structures made of reinforced concrete or timber (5). This creates significant potential for reusing steel in load-bearing structures. For example, in the K.118 stockpiling project in Winterthur, Switzerland, the reuse of a bolted steel structure resulted in only 8% higher costs but 90% lower greenhouse gas emissions than a comparable new steel structure. Approximately 70% of these savings were attributed to reduced transportation needs over distances exceeding 120 km (6). One advantage of reusing steel structures is that they are usually designed and standardized as mullions. Dimensions can be measured in the installed state when accessible (7).

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Determining the steel grade used is more challenging, as historically there was no obligation to mark components accordingly. Only EU regulations that came into force in 2024 require a Digital Product Passport (DPP) for physical products within the EU by 2030 (8). Beyond steel grade, assessing intactness, surface treatment, abrasion and machinability is essential for comprehensive quality verification, often by researching the component history alongside mechanical or non-destructive tests (7,9).

uptownBasel is transforming an existing industrial site into an international competence center for Industry 4.0 in Arlesheim, Switzerland (10). The site offers excellent potential for local reuse, as dismantling operations, factory floors, storage areas and installation sites are all in close proximity (11). Building G8, scheduled for dismantling, is a former industrial hall with a visible and directly accessible load-bearing steel structure. Some of the steel profiles will be reused on-site by the same owners shortly after dismantling, while others will be stored on-site and made accessible for later construction work by the same owners. Accessibility refers both to storage and physical accessibility, as well as to the accessibility of information regarding available components and their storage locations. As there is currently no standardized and proven procedure for handling dismantled steel profiles to ensure the greatest possible accessibility, this study aims to develop recommendations for uptownBasel that can serve as a foundation for comparable projects.

2. Methods

Research and application questions were formulated to develop recommendations for handling dismantled steel profiles for reuse in uptownBasel. The main research question was: How can dismantled steel profiles in uptownBasel be made physically and digitally accessible? Sub-questions regarding physical accessibility addressed storage space requirements, while those concerning digital accessibility focused on information requirements and technologies suitable for the unique and unambiguous identification of the dismantled steel profiles for reuse. To answer these questions, the authors of this study first researched the status quo through scientific literature (publications, standards, product catalogs, and case studies). Possible solutions were compared and evaluated by using the Choose by Advantage (CBA) method, a structured decision-making process for selecting the optimal option for the specific uptownBasel case based on the significance of various advantages. Finally, the results were validated in an on-site workshop in 2023 led by the authors together with clients, planners, and executing contractors from the uptownBasel project. Eleven key project participants took part in the workshop, discussing the literature review results and answering related questions prepared by the authors using Mentimeter as an app for real-time feedback. This enabled immediate evaluation of survey results within the workshop alongside expert input.

3. Results and discussion

3.1 Information management for the reuse of steel profiles

To simplify future steel profile reuse, data can be collected in Material Passports (MP). MPs are structured (digital) data registers or datasets that clearly identify materials and components, describe their characteristics, and make them accessible for current and future use or reuse (12). The Swiss construction industry currently employs various solutions for MPs and databases, depending on specific uses and providers (13). Due to the lack of a standardized solution, uptownBasel opted for its own database, considering what information is needed for whom

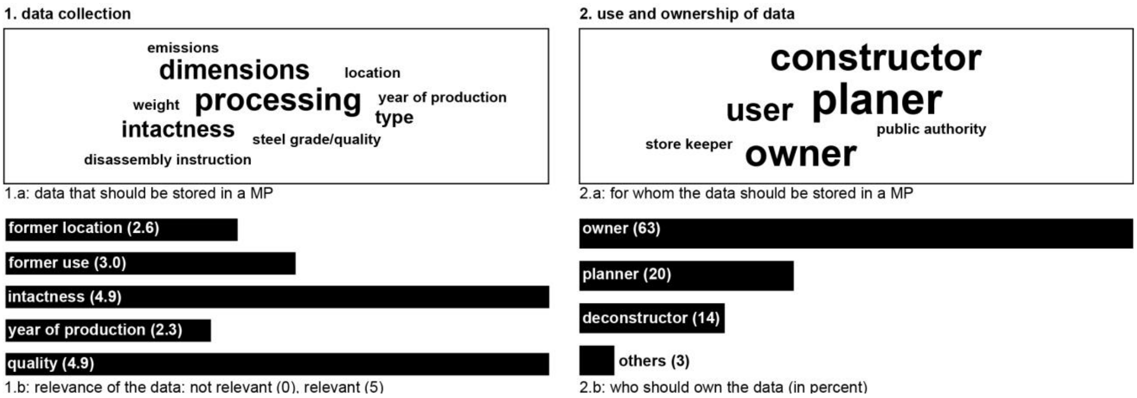

Figure 1. Mentimeter results for 1. data collection and 2. use and ownership of data. *Source*: Based on (9).

(clients, planners, contractors, future users, and authorities) and when (before, during, or after construction). Other requirements identified by workshop participants include considerations for data collection, use obligations for stakeholders, and the degree of automation (automated, semi-automated, or manual), which influences the choice of technologies and processes (9). Based on the data requirements defined by the literature review and the workshop discussions, information types were determined and categorized (see Figure 1 and Table 1).

A distinction was made between constants and variables. Constants include steel grade, year of manufacture, and a unique and unambiguous Identification Number (ID). The market leader in the global management of partial information using unique identification numbers is the Global Standards 1 (GS1) association, which uses a Global Trade Item Number (GTIN) as a unique identification key (14). While dimensions can change (e.g., due to cutting), workshop participants considered it less likely that the component type would change, such as when beams are welded together to form a taller beam or modified to form a honeycomb beam (9). The need for processing (e.g., sanding and coating) was also deemed relevant when selecting suitable technologies and processes, indicating that certain data is dynamic and must be modifiable. Processes that keep the information up to date and consistent as automatically as possible were considered important. Regarding data types, the authors identified distinctions between numeric attribute data (digits) and alphanumerical attribute data (digits and characters). Additionally,

Table 1. Data matrix of steel profiles. *Source*: Based on (9).

Category	Information	Example	Data type[a]	Determinability
Constants	ID[c]	0001	N	Freely or generated as GTIN
	Steel grade/quality	C45	A	By origin or measurement
	Year of production	1900	N	By document analysis
Variables[b]	Dimensions	330x160x600mm	N V	By measurement
	Type	IPE 330	A V	By dimensions or document analysis
	Weight	1 t	N	By dimensions, type and quality
	Emissions	1,65 t CO_2-eq	N	Approximation by measurement
	Intactness	Rust, damage	A V I	By inspection and/or measurement
	Processing	Coating	A	By inspection and/or measurement
	Location	Roof	A V I	By inspection and/or measurement
	Type of use[c]	Longitudinal beam	A V I	By inspection
	(Dis)assembly Instr.	Screw	A V I	By inspection

[a] N = numeric attribute data, A = alphanumeric attribute data, V = vector data, I = image and raster data. [b] To distinguish between existing and planned/expected. [c] Added to the workshop results based on literature review of the authors.

vector data (depicting objects geometrically using points) and image/raster data offer possibilities for displaying information. According to workshop participants and literature review, additional information (e.g., defects) can be stored in writing, plans and images linked to the raster data (9). In the K.118 project, for example, components were provided with warehouse numbers and printed component passports including rough dimensions, sketches, photos, and information on special features, manufacture, and year of production (15).

3.2. Inventory management

Inventory management is key to determining appropriate technologies and processes. According to the authors' literature review, basic distinctions can be made between weather-protected and unprotected locations, and between sorted and unsorted storage structures. Steel profiles sorted by type are an example of sorted storage. Components could also be stored unsorted and assigned to unique and unambiguous storage locations via IDs, similar to a library system. In this case, documentation and marking become necessary to locate components. Depending on the number of similar components in uptownBasel, the workshop participants introduced a sorting system (see Figure 2). They found that components could mainly be stored next to each other and only infrequently needed to be stacked on top of each other due to the generous amount of space on site, making a shelving system unnecessary (9). During the workshop, 75% of participants assumed that the warehouse would be exposed to the weather and that physical damage to potential markings could not be ruled out (9). Regarding the expected storage duration, 70% of workshop participants estimated several years, 30% estimated only several months and none expected decades-long storage (9). 90% of respondents anticipated multiple changing storage locations, such as sorting areas or interim storage facilities (9).

Figure 2. Building G8 uptownBasel assembled and disassembled. *Source*: Photos by the authors, 2023/24.

3.3. Technologies

Component marking and a data collection can make component information accessible in the long term (16). Technologies enabling object tracking are known as Track and Trace (T&T). While these have been used extensively in areas like food production, where supply chain traceability is essential, their application in construction remains largely unexplored (16). The construction industry's long usage cycles for components present unique implementation challenges (16).

3.3.1. Technologies for marking capabilities and connectivity

Marking either contains directly human-readable information or provides a link to machine-readable information (see Table 2). Human-readable marking (HRM) is the oldest and most widely used component marking method in construction. Components receive directly readable designations and, if necessary, additional object information. Construction sprays or labels are often used on construction sites, though the durability of both solutions depends on weather conditions and on-site component processing. The K.118 project exemplifies the use of HRM in a sorted warehouse (15). When stamping components, it is important to consider which information is relevant and constant (compare Table 1). It is also important to consider where the markings are placed so that the information can be easily read.

Table 2. Comparison and evaluation of technologies for marking options and connectivity. *Source*: Based on (9).

	HRM	DMC	NFC	RFID
Example	Spraying, engraving, printing (e.g., label, laminated paper, adhesive foil)	Engraving, printing (e.g., label, laminated paper, adhesive foil)	Chip (e.g., in adhesive foil or built-in)	Chip, magnetic board (e.g., in adhesive foil or built-in)
Advantages	Simple; no training required; easy to apply on steel; provisional or permanent	Simple; no training required; later changes to data possible; easy to apply on steel	Later changes to data possible; markings can be built into objects (but not into steel)	Later changes to data possible; markings can be built into objects (but not into steel)
Disadvantages	No later changes to data possible; markings visible	Markings visible	Visible on steel; sensitive (damage) for further processing	Visible on steel; higher costs for initial purchase
CHF per unit	0.10 – 2.00	1.00	1.80	8.20

The Data Matrix Code (DMC) is an optoelectronically readable code that stores information in encrypted form. DMCs require a reading device with visual contact to the code to access the encrypted information. It is particularly common in the food industry in the form of barcodes. Another example is the Quick Response (QR) code, which can nowadays easily be read with smartphones. DMCs can be applied using carrier material (e.g., stickers, badges) or engraved directly into the component, depending on the material (16). The durability and fineness of engraving in steel profiles can be seen as an advantage of the material. The exhibition pavilion House of 1000 Stories in Konstanz, Germany, provides an interesting DMC application case: It was assembled entirely from dismantled parts from the surrounding area (17). Each component was provided with a QR code making its origin and history traceable for visitors using smartphones, generating a virtual tour of the respective demolition site (18).

Near Field Communication (NFC) is widely used for contactless data transmission in payment services like credit cards (14). NFC data transmission occurs in the high-frequency range, limiting reading distance to just a few centimeters, depending on the technology – a feature that enhances security but hinders locating specific steel profiles in an unsorted storage (14). NFC enables both unilateral and bilateral information exchange (14), meaning an NFC device can function both as a tag with readable information and as a reader (14). One construction sector application is in tunnel maintenance, where NFC tracking helps identify similar-looking tunnel segments over long distances, enabling defective components to be located (19). To achieve this, the chips were cast within the segments; which is possible for a concrete structure but not feasible for a steel structure. This means that the chips can only be surface-mounted in the uptownBasel case.

Radio Frequency Identification (RFID) is a contactless data exchange technology based on electromagnetic waves. Both passive and active transponders exist. With passive transponders, information can be read using a reader with an antenna and the electromagnetic field generated by the reader (14). The antenna requires minimal energy and therefore has a service life exceeding 10 years (20). The range of passive transponders depends on the frequency (low, high, and ultra-high) and varies between 0 and 10 meters (21). Active transponders have their own power source and can achieve ranges of up to 100 meters (21). One example of RFID technology is in retail security: A passive transponder reacts when goods come close to the exit of a store where the active transponder is located (14). RFID chips are particularly valuable for tracking circulating items where availability and quantity are important, for example, in an unsorted warehouse in which the components and their quantities are constantly changing. An example of RFID in circular construction is the Lumi property in Uppsala, involving the renovation of several buildings (22). Since components may remain in the neighboring buildings as unsorted interim storage for uncertain periods of time, the Byggstyrning company chose to employ RFID technology (23). When someone approaches the storage with a reading device, a component list is automatically generated (23). To locate a specific component, the person with the reading device approaches the presumed location of the object.

The aforementioned marking technologies were evaluated for uptownBasel based on the following criteria: approximate costs per unit (e.g., of a tag) and the total costs, including all work required to apply the tag to the steel, feasibility (of the implementation of the marking on the steel), durability (the robustness and service life of the marking technology) and accessibility (the readability of the technology from a distance). Based on the evaluation of the workshop feedback, the authors of this study recommended a combination of HRM, DMC, and RFID marking technology in one tag for the uptownBasel use case: a small amount of key information (constants) can be read out directly, while additional information (variables) can be accessed indirectly via a database. The basic effort is similar regardless of marking form, and considering the unknown future requirements for steel load-bearing structures across multiple life cycles, it make sense to account for these from the outset by using a combination of marking technologies (16). The combination of different technologies also enables a distinction to be made as to which information can be read and by whom and when.

3.3.2. Technologies for data storage

Data storage is crucial for reading, backing up, and sharing information. System-neutral data usability plays a particularly important role. Examples of data storage technologies include text-based files, spreadsheet software, web applications, and Industry Foundation Classes (IFC). As with digital data provision in general, the difficulty lies in ensuring the accessibility of the data for decades to come (see Table 3).

Text-based file formats such as JSON, ASCII or CSV follow simple structures. The basic information, the description of the structure of the data (header block) and the other content are stored and marked in the file. Text-based formats can be easily read and processed by many

Table 3. Comparison of technologies for data storage. *Source*: Based on (9).

	Text-based files (e.g., JSON)	Spreadsheet software (e.g., MS Excel)	Web application (e.g., MS Power Apps)	Digital Building Model (e.g., IFC)
Advantages	Simple and provider-independent; widespread technology	Simple and provider-independent; widespread technology; incl. calculation software	Scalability of functions using web connections; individual authoring software possible	In combination with DBM; internationally recognized and open standard
Disadvantages	Information must be interpreted by people	Information must partly be interpreted by people	Depending on pricing models of providers	Effort for creating a DBM

systems. However, the information recorded leaves room for interpretation by the reader. Spreadsheet software like Microsoft Excel (MS) table allows information to be entered manually or automatically. Both text-based file formats and digital spreadsheets can be managed online, enabling several people to access at the same time. Web application technologies serve as interfaces to data storage formats. Information can be saved and shared in a tabular structure via cloud services and individually linked to other web services. Data storage using web applications could be integrated using low-code applications – development environments enabling simple, visual programming without extensive information technology or programming knowledge.

In the late 1970s, the idea of product modelling emerged as a comprehensive digital product description approach, including both geometry and semantics (24). Industry Foundation Classes (IFC) are a machine-readable, standardized data model and format for mapping and exchanging Digital Building Models (DBM). Maintained by buildingSMART International as ISO 16739-1:2018, the first version (IFC 1.0) was published in 1997, with implementation in construction-specific software packages beginning from version 1.5.1. Through additional international standardization (25), the file format is becoming increasingly important for the public sector and is already established in some countries as a binding exchange format for procurement and approval procedures. Since IFC version 4.0, the PSet_Manufacturer-TypeInformation contains the GTIN attribute (25). In the Lumi project, unique ID numbers ensure that real objects can be assigned to digital objects through 3D elements stored in a BIM authoring system (23). Standardized library elements are used for reused components, specifically adapted where necessary and supplemented with additional information, such as new surfaces or construction site processes (23). The latter is particularly relevant for warehouse logistics. Expected emissions are recorded for each component, allowing variant comparison during the design process (23).

For data storage technologies, the study's evaluation focused on the effort required to create and maintain the data. Since a 3D model already existed for uptownBasel and the corresponding work has been completed, the authors of the study recommended that the data be stored in this model. However, the workshop discussions also considered using the existing Excel document due to its advanced level of detail. From the exchange with the workshop participants, it was concluded that the choice of suitable technology for data storage depends less on the material, in this case the steel to be reused, and more on the team and possibly already existing working methods or future processes.

3.4. Processes

The integration of reused load-bearing components into construction processes changes not only the processes themselves, but also the roles, tasks and responsibilities of individual participants (26). This requires different cooperation and contract models, especially regarding guarantees, as

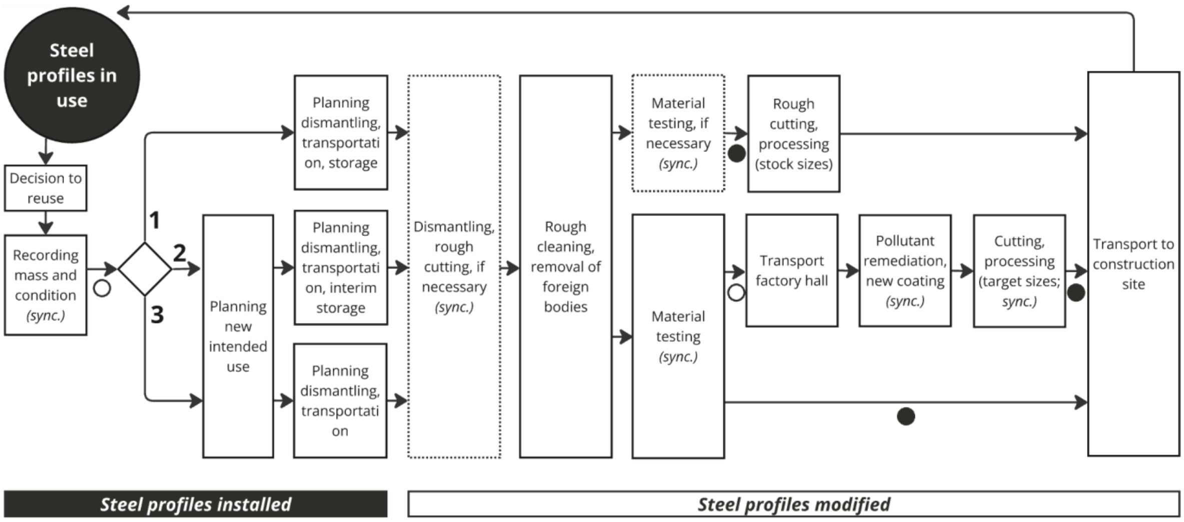

Figure 3. Process matrix (*sync.* = synchronization of data; 1= storage for later reuse: 2 = reuse after modification; 3 = direct reuse; ○ = provisional marking, ● = permanent marking). *Source*: Based on (9).

well as a different mindset. Instead of opposing interests, integrated and cooperative models of project management become necessary (27). In the K.118 project, for example, components considered for reuse prompted detailed considerations into the project design at an early stage, which, in turn, influenced the entire project (6). The polygonal floor plan of the existing structure contrasted with the reused rectangular steel structure. Rather than laboriously shortening the steel structure, it was mounted in a cantilevered manner, creating today's characteristic shape (6).

This study examines the process steps in the uptownBasel case in detail, focusing on the storage and synchronization of data as well as component marking (see Figure 3). Initial process steps include establishing requirements for component reuse and selection of MP and database systems by the clients. The planners are responsible for researching the history and construction of the building, the identification of components for reuse, and conducting material testing (9,13). Before dismantling, data for components suitable for reuse must be recorded and stored in a database using an MP (e.g., dimensions, carrier type and designation). An ID is only necessary to a limited extent for the many similar components without specific vulnerabilities. Additionally, planning for the target use of the components should be addressed, such as through algorithmic assignment of components, along with planning for the dismantling, transport, and storage of the largest possible units considering component weight, transport dimensions, as well as the risk of damage during handling. Early contractor involvement, as in Integrated Project Delivery (IPD) projects, is important in this context (27). It may be necessary to provide a temporary provisional component marking (simple, inexpensive) with minimal information about dismantling, transport, and storage (e.g., rough cutting with lines, storage location symbols using construction spray) by planners or contractors, as early component marking and continuously updated MPs ensure information consistency (9). Before storage, components must potentially be cut, transported, cleaned, coated (e.g., corrosion protection, sandblasting) and marked with long-term identification (e.g., combination marking technology: HRM, QR, and RFID; weatherproof, visible, and design-coordinated). Additionally, new data must be stored in the MP by the planners and/or contractors, depending on which future applications are to be considered. The procedure must be differentiated and repeated depending on whether components will be stored as-is, modified before reuse, or reused directly.

4. Conclusion

4.1. Summary
Consistency in information management can be seen as a basic prerequisite for circular construction. The components essential to selecting suitable technologies and processes for the steel to be reused in uptownBasel include the available elements, the MP, specific application information requirements, and the stock management process. Effective information management (whether analogue or digital) with corresponding accessibility and traceability makes a significant contribution here. Only when the existing information is accessible and clearly assignable, for example through a structured database stored in a DBM or Excel, can it be effectively used for planning and construction. The discussion in this study indicates that while the reuse of used components must be considered individually for each application, certain technologies and process steps can be applied universally to create synergies. Component marking and data storage represent additional expenses. To justify these costs, future benefits must be determined on a project-specific basis. In uptownBasel, there is the rare case where the removal and reinstallation of steel profiles is to be carried out at the same location with the same owners. Additionally, a steel construction company is in the immediate vicinity. This creates enormous potential to minimize transportation routes and corresponding greenhouse gas emissions. Since the steel profiles for reuse are robust and generous open space is available, a sorted outdoor storage area is an obvious solution. Furthermore, having a single owner simplifies implementing a dedicated database and streamlines the process. It makes sense to pursue a storage solution based on the existing structures of the project team. By using a combination of marking technologies, independence, openness and longevity of information and their further use is ensured. As this study demonstrates, building with reused components transforms established processes. While conventional planning is followed by the selection of materials, planning with reusable components requires considering the available components from the beginning.

4.2. Outlook
The questions of what information should be stored and extracted for whom and when, and to what extent (partially) automated, were outside the scope of this study, but would be of interest for further studies. Additionally, it would be interesting to monitor and evaluate the processes in uptownBasel that have been initiated since 2024 and are still ongoing, to continue learning from the implemented application. Since planning with reused components requires transdisciplinary cooperation from the outset as well as new contractual and insurance models, especially for load-bearing structures, forms of cooperation such as IPD or Alliance Models warrant further exploration. Software that uses algorithms to allocate components according to definable criteria could facilitate planning with load-bearing steel elements and lead to greater reductions in greenhouse gas emissions. For example, Generative Design could be used to determine where a full profile fits and where it makes sense to weld two profiles together as complete units or as honeycomb beams. If these scenarios could be tested (partially) automatically, a comparison could identify the lowest material consumption as well as the lowest impact through greenhouse gas emissions (e.g., through reduced welding activity or surface treatment requirements).

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