DESIGN FOR ASSISTIVE TECHNOLOGY APPLICATIONS: USEFULNESS OF RE-USE?

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Abstract

Due to an increased need for Assistive Technology (AT) applications, governmental interest into reducing the total cost of providing AT applications is growing. A commonly reported high rate of AT abandonment indicates a potential for recovering unused AT and re-introducing it into the pool of available AT applications. In this paper we perform a literature review of waste management concepts from the 'Waste Hierarchy' process, and translate these concepts into concepts applicable for AT, with the intention of investigating the potential of re-use (including constraints and conditions) as an attempt to battle the increased health care cost of AT due to an aging population. The key problems and issues, when translating these concepts to the specific needs of the AT market, are highlighted. Re-use concepts that strictly fall outside of the definition of re-use are addressed.

Keywords: Assistive Technology, Design for Re-use, Re-manufacturing, Waste Hierarchy, Product lifecycle management (PLM)

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1 INTRODUCTION

Due to a shift in the population pyramid (Hayutin, 2010), where an increasing percentage of the elderly population will have to be supported by a decreasing percentage of the active population, it will become progressively more difficult to maintain the social contribution required to finance Assistive Technology (AT). Although the term 'assistive technology' is frequently used and generally understood, there is no universally accepted definition. We will use the definition provided by Hersh & Johnson (2008)

> *Assistive technology is a generic or umbrella term that covers technologies, equipment, devices, apparatus, services, systems, processes and environmental modifications used by disabled and/or elderly people to overcome the social, infrastructural and other barriers to independence, full participation in society and carrying out activities safely and easily.*

We believe re-use can make a significant contribution to lowering these costs. It is a common understanding that there is a high level of AT abandonment, as stated in Hersh (2010); Armstrong et al. (2010); Hamidi et al. (2014); Desideri & Roentgen (2013); Federici et al. (2014); Wessels et al. (2003). Many papers reference Phillips & Zhao (1993) who state a level of AT abandonment of up to 30%. More recent research analyzing the current state of AT abandonment states that this percentage may be lower, Dijcks et al. (2006) state an AT abandonment rate of less than 10%. They suggest that this reduced rate may be caused by the strict criteria required for refunds by health care insurance companies. Federici & Borsci (2011) report an AT abandonment rate of 25%. It is the authors' view that the large variations in these results are caused by the complex nature of AT abandonment and the diversity of the examined target groups. Extensive research analyzing the current state of AT abandonment however seems to be lacking. A possible solution for gathering more knowledge on AT abandonment is setting up service models that, among other things, could detect AT non-use (Andrich & Mathiassen, 2013). Re-introducing the abandoned AT into the pool of available AT products, potentially at a reduced price, could help tackle the costs due to the increased need for AT.

While no research could be found analyzing the re-use activities in Europe, it is the authors' view that currently only a limited amount of re-use of Assistive Technology is performed in Europe, usually organized by local non-profit organizations. We expect that this limited amount of re-use is a result of the financial models frequently used in Europe, where the purchase of new Assistive Technology products is often fully funded by the government (European Commission, 2003).

When discussing the potential of re-use within Assistive Technology it is important to clarify the meaning of the word 're-use'. The ambiguity of the word has lead to many different definitions (Watelet, 2013). The definition used by the StEP initiative (StEP, 2009) is:

> *Re-use of electrical and electronic equipment or its components is to continue the use of it (for the same purpose for which it was conceived) beyond the point at which its specifications fail to meet the requirements of the current owner and the owner has ceased use of the product.*

The term re-use is most commonly associated with 'waste hierarchy'. Waste hierarchy is a process used to protect the environment and preserve resources through a priority approach established in waste policy and legislation (Hansen et al., 2002). It indicates an order of preference for action to reduce and manage waste, and is usually presented in the form of a pyramid (United Nations Environmental Program, 2013). Many variations exist but all give the same general message. The different tiers of the pyramid are:

- Prevention: Minimize the generation of waste products.
- Reuse: Reuse products or components for the same purpose for which they were intended.
- Recycle: Sort and process recyclable products into raw material and then re-manufacture the recycled raw materials into new products.
- Recovery: Recover energy through composting and waste incineration with energy recovery
- Disposal: Landfill and waste incineration without energy recovery

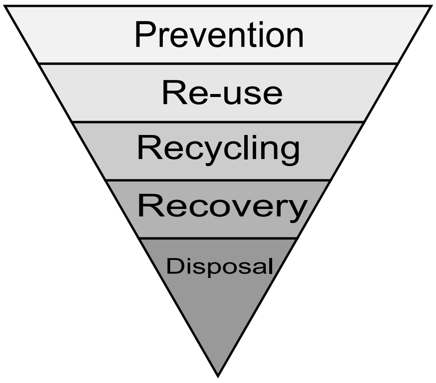

Figure 1. Waste Hierarchy piramid based on Hansen et al. (2002)

In this paper we translate the waste hierarchy concepts to design concepts for AT in an attempt to battle the increased health care cost due to an aging population. Due to the relatively small target group of AT, the relative economical impact of the lower tiers of the pyramid will be small and will be ignored in this paper. For the other tiers an analogy can be made, not from an ecological point of view, but from an economical point of view, where waste is seen as the sub-optimal use of Assistive Technology resources.

2 ASSISTIVE TECHNOLOGY WASTE HIERARCHY

2.1 Prevention

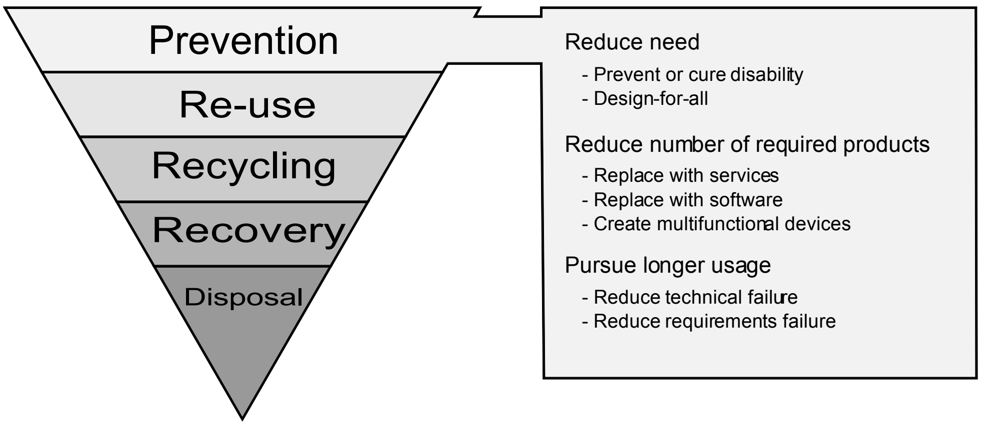

Figure 2. Main topics concerning prevention

The most important tier from the waste hierarchy is prevention. For AT this exists on multiple levels. First one could strive to prevent the need for AT devices. Either through the prevention or curing of disabilities, or through design-for-all strategies, where products, services, and environments are designed in such a way that they are accessible and usable for the widest possible audience, obviating the need for later modifications.

A second level of prevention is obtained by reducing the number of required products, either by replacing hardware with a service, e.g. by replacing product sales with rental services, or by replacing hardware with software alternatives, e.g. replacing hard drives with cloud storage. Both examples still require hardware, but the total number of products can be reduced. Similarly, the number of required products can be reduced by providing products which allow multiple functionalities, e.g. a mobile phone that can be used as phone, GPS, music player,...

A third level of prevention is obtained by increasing the lifespan of a product, reducing the need for new products. The reason for non-use of a product can result from either a technical failure (a), where the product cannot perform its functions any longer (due to failure or fatigue, software compatibility issues or connectivity issues with other devices), or requirements failure (b), where its specifications fail to meet the requirements of the current owner and the owner has ceased use of the product.

(a) Preventing technical failure can be obtained through a durable design. It should however be noted that, from an economical point of view, the increased cost (percentage wise) should not be larger than the increased estimated life expectancy (percentage wise). For example, increasing the life expectancy of a product with 20% with an increased cost of 40% is not economically viable. Note that the total cost of ownership, including end-of-life processing costs, must be taken into account.

Non-use of a product due to technical failures should not automatically mean the end-of-life of the product. As long as the residual value of the product is higher than the repair cost, repair should be considered. Reducing the repair cost can hence be seen as a viable way of increasing the usable life of a product. Note that the repair cost does not only include material and personnel costs, but also costs related to transport, administrative overhead, stocking,...

(b) Requirements failure in its most extreme form is when the product is never used. Many factors can cause the non-use of a product (Wessels et al., 2003). These include personal factors (e.g., not coming to terms with a newly acquired disability), device related factors (e.g., poor quality, highly stigmatizing, not user friendly,...), environment related factors (e.g., the presence or absence of social support, legislation concerning refunds,...), and intervention-related factors (e.g., non-inclusion of the user's opinion when selecting a device, absence of a follow-up service,...).

While some of these issues can be addressed by adapting AT design practices, some AT abandonment is caused due to limitations in the service delivery process (Andrich & Mathiassen, 2013). For example, missing competences when selecting or implementing (configuring, fitting, learning to use,...) an AT device could lead to the selected device not meeting the end users' expectations. While this is not the target of this paper, it is clear that more research must be done to optimize the service delivery process.

AT design should make use of common design practices to avoid previously stated issues. These design practices include, but are not limited to, user centered design, iterative design and development, multiple-criteria decision analysis, and compliance with standards. There are however some design practices specific for AT. Since, at least in most European countries, the insurance companies or the governmental organization, and not the actual users, are responsible for financing the purchase of AT, these stakeholders should be included in the design process from an early stage. Another issue with traditional user centered design is that, due to the nature of the disability of the end user, it can be challenging to include the end user in the design process. A final issue specific for AT is that, quite commonly, AT devices are developed for a small number of users, leading to expensive devices due to the absence of 'Economy of Scale'. During the design phase one must examine whether the social cost, resulting from the lack of the AT device, justifies the expected high production cost.

An other reason for the abandonment of a product due to requirements failure is the lack of adaptability to the changing requirements of a user over time. These changes can occur, for example, due to evolution of a disease, increased/decreased confidence of a user, or even the availability of new, better alternatives. This could be addressed by designing products that are extremely adaptable and customizable, for example by using a modular design where components can be grouped according to functionality. The chosen design approach should balance adaptability with usability, since the increased complexity due to modularization could lower the usability of the system.

2.2 Re-use

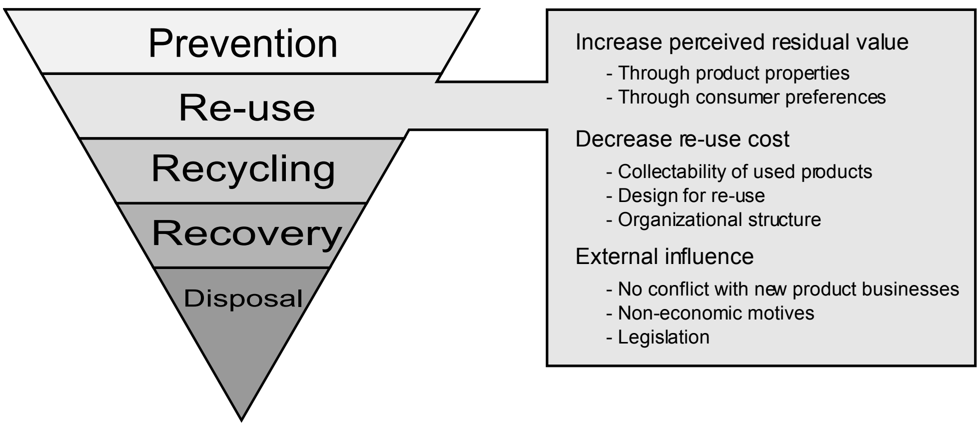

Figure 3. Main topics concerning re-use

In this section, we will start by discussing general factors influencing re-use, followed by a discussion of specific factors influencing AT re-use.
A number of studies have been performed that have highlighted a number of issues concerning re-use. While many studies have a focus on re-manufacturing, the definition of re-manufacturing differs greatly between authors. In some cases the term re-manufacturing is used to describe the process of reusing components from one product, to create a totally different product. In other cases the term re-manufacturing is used for the process of repair and/or refurbishment of products, usually with the intent of returning them to an 'as new' state. In this paper we propose our own definition.

> *Re-manufacturing encompasses the repair, upgrade or refurbishment of products by reusing components, both for the original user (prevention) as subsequent users (re-use), and the use of reused raw materials in the manufacturing process (recycle).*

It has been stated that re-use is viable only when it is cost effective (Kniskern et al., 2008; Villalba et al., 2004). This means that the perceived residual value of the product must be greater than the cost of re-using the product. Based on this statement, and on the criteria required for re-use discussed by Matsumoto (2010), we can define following factors influencing re-use opportunities:

1. Perceived residual value
    a. *Product properties*
    b. *Consumer preferences*
2. Re-use cost
    a. *Collectability and redistribution of used products*
    b. *Design for re-use*
    c. *Organizational structure*
3. External factors
    a. *No conflict with new product businesses*
    b. *Non-economic motives*
    c. *Legislation*

While these factors will usually be intertwined, to reduce complexity, we will discuss these factors as separate topics in more detail below, omitting the reasoning for why stakeholders would want to influence re-use opportunities. Each major section will be followed with factors specifically influencing AT re-use.

2.2.1 Perceived residual value

We can define two major factors that influence the perceived residual value of a product, namely product properties and consumer preferences.

Product properties

Two product properties are often highlighted: (1) the rate of technological innovation, where a high rate of technological innovation leads to the desire of replacing rapidly evolving products or components, leading to a lower perceived value, and (2) a product's physical lifespan, where a short physical lifespan leads to a product being unsuitable for re-use. Another factor that will influence the possible re-use of a product is the initial value, since the residual value will be a fraction of the initial cost, and the residual value must be greater than the re-use costs. This means that products with an initial lower value, or with a high rate of technological innovation are de facto not suitable for re-use. Increasing the products' physical lifespan is a valid approach to increasing the perceived residual value, and can be obtained through a durable design approach, as already mentioned in the section on prevention.

Consumer preferences

The intention to purchase re-used products is defined by several factors. Factors positively influencing purchase intention can be, but are not limited to, economic reasons, based on the reduced price of re-manufactured or re-used products, and ecological reasons, based on the reduced energy required to re-manufacture products and the reduction of waste generation. Factors negatively influencing purchase intention are commonly described as an increased perception of inferior performance and durability, leading to an increased perception of risk, and a reduced intention to purchase re-used products (Wang et al., 2013; Guiot & Roux, 2010). While little research on the subject could be found, it is the authors' view that emotional and psychological barriers caused by a potential stigma of re-used products should not be neglected as a potential factor negatively influencing purchase intention of re-used products.

Possible solutions for influencing the attitude towards re-used products are initiatives such as the British PAS 141:2011 standard, which provides guidelines and certification for re-use processes aimed at improving the perception of reliability of re-used products.

AT application

Applying these principles to AT, we can state that due to the small target group of AT devices, the price of high tech AT devices is generally high. This, in combination with a common rapid change in user requirements, would mean that there is a high likelihood that AT devices will have a significant residual value at the point at which its specifications fail to meet the requirements of the current owner. It should however be noted that reliability, quite commonly, is an important requirement for AT devices, which might conflict with the perceived inferior performance and durability of re-used products. It is the authors' view that great care must be put into increasing the reliability and the perception of reliability when re-using AT products.

2.2.2 Re-use cost

The main factors influencing the re-use cost are the collectability and redistribution of used products, design issues related to optimal facilitation of re-use, and the organizational structure of businesses implementing re-use.

Collectability and redistribution of used products

One of the main issues with the collectability of used products is a lack of control regarding timing, quality and quantity of returned products. The establishment of an efficient reverse logistics network, where products are returned to the supplier, and the management of unpredictable returns, is crucial for the success of re-use businesses. Possible closed-loop supply chain relationships (Östlin et al., 2008) are

- Service based[1]: The product is rented, leased, or offered as a service, e.g. product-service systems. Ownership remains with the supplier of the product.
- Contract based: A service contract exists between supplier and customer that includes re-manufacturing. Ownership is transferred to the user of the product.
- Direct-order: The customer returns the used product, as an individual order[2].
- Credit-based: When returning a used product, a discount is received for the purchase of a new (re-manufactured) product.
- Buy-back: The manufacturer buys back the used product from the customer, or a third party supplier.
- Voluntary-based: The customer donates the product to the re-manufacturer, either directly or through third party suppliers.

A detailed analysis of the advantages and disadvantages of each of these closed-loop supply chain relationships is outside the scope of this paper.

Design for re-use

The re-manufacturing process required for re-using a product or component can include the following tasks: inspection, disassembly, cleaning, reprocessing, and reassembly. Design methods that can reduce the effort required for these tasks can have a positive influence on the success of re-use. No detailed list of design guidelines could be found in the literature. This is probably due to the fact that most studies concerning re-manufacturing are based on a limited number of cases, and what enhances re-manufacturability for one product or process, may differ from another. A list of general guidelines can be generated based on the results from previous studies (Ijomah et al., 2007; Zwolinski et al., 2006; Sundin & Bras, 2005; Watelet, 2013).

- Allow for non-destructive disassembly and cleaning
- Arrange components
  - for ease of access
  - for ease of identification
  - by grouping components with similar life expectancy

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[1] Östlin et al. (2008) use the terms 'Ownership-based' and 'Service-contract' for respectively 'Service based' and 'Contract based'. These where changed to increase clarity.

[2] While the most common example of this supply chain relationship can be found in 'direct-order' repair services, and repair services are not part of our re-use definition, it was kept in this list for completeness.

- Reduce complexity
  - by limiting number of parts (simplify design)
  - by limiting number of joints and fasteners
  - by limiting number of different materials
  - by limiting number of fastener types
- Allow easy handling
  - by using components sized for easy handling
  - by providing realistic tolerances to allow movement during disassembly
- Allow easy identification
  - by emphasizing recognizability of disassembly points
  - by providing permanent identification of material types such as barcodes (wich should be properly arranged as mentioned earlier).
- Allow easy testing

Previous research has attempted to create design methods and tools to facilitate design for re-use (or re-manufacturing). However, there is little evidence that suggests that any of these tools are commercially available (Hatcher et al., 2011).

Organizational structure

An organizational structure, that increases the communication and knowledge sharing between business departments/divisions, greatly increases the chance of success of a re-manufacturing business. Taking into account issues like total cost of ownership and a product life cycle focus on a global level, by integrating product marketing, design and distribution, is a key to re-manufacturing success (Subramoniam et al., 2009).

AT application

While design methods exist that optimize cost reduction in re-manufacturing processes, it is clear that without an elaborate reverse logistics network re-use seems unlikely. Although not explicitly mentioned, the previously described cost reduction methods are based on large volumes and will likely have an increased benefit with larger volumes. The target group of AT devices is still relatively small such that the quantitative effect of these cost reduction methods is unclear and requires further research. It is the authors' view that, due to the lack of 'Economy of Scale', the potential of small scale production technologies like 3D-printing is very high. This potential is also considered high concerning customization or repair of AT devices.

2.2.3 External factors

While the residual value and the re-use cost directly influence the opportunities for re-use, there are also some external factors that can influence re-use opportunities. These include the absence of conflict with new product business, non-economic motives, and legislation.

No conflict with new product businesses

To avoid re-manufactured products potentially cannibalizing the demand of new products, some original equipment manufacturers (OEM) choose not to sell re-manufactured products. Whether cannibalization actually decreases the overall profitability is still subject for debate. Some researchers argue that consumers do not distinguish between new and re-manufactured products (i.e., re-manufactured products are perfect substitutes for new products). At the other extreme, some research provides evidence that consumers of new and re- manufactured products are segmented, and therefore there is no cannibalization at all (Guide Jr. & Li, 2010). While some researchers conclude that the entry of a third-party re-manufacturer is detrimental for the OEM and that it is profitable for the OEM to re-manufacture or collect products to preempt third parties (Atasu et al., 2008), Agrawal et al. (2012) states that third-party competition may actually be beneficial for an OEM due to the positive effect of third-party re-manufactured products on the perceived value of new products.

Non-Economic motives

In some cases the decision to undertake re-use businesses is not only influenced by direct profitability, but also by long term corporate strategies. Factors including secure spare parts supply, ethical responsibility and brand protection have been stated as reasons for undertaking re-use businesses (Aurich et al., 2006; Östlin et al., 2008; Kissling et al., 2012).

Legislation
Legislation can greatly influence re-use business. For example, to improve the environmental management of waste of electrical and electronic equipment (WEEE) and to contribute to a circular economy and enhance resource efficiency by the improvement of collection, treatment and recycling of electronics, two pieces of legislation have been put in place: The Directive on waste electrical and electronic equipment (WEEE Directive 2012/19/EU) and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS recast Directive 2011/65/EU) EU (n.d.). The WEEE directive aims to promote reuse and recycling by imposing collection and recovery quota and to reduce e-waste by enhancing the eco-design of products. The RoHS directive restricts the use of hazardous materials in the manufacture of various types of electronic and electrical equipment.
AT application
The influence of legislation in the AT business is very high compared to the businesses mentioned in the analyzed literature. Although AT Service delivery systems are part of the local welfare system, and thus the way in which they are organized differs greatly in the various European countries or regions, the same policy principles apply (Andrich & Mathiassen, 2013). A detailed analysis lies beyond the scope of this paper, but it can be stated that most European countries or regions have a high level of refunding of AT, either through governmental organizations or private health insurances (European Commission, 2003).
Based on the analysis of re-use businesses we can state two possible opportunities for re-use within AT. Due to certain limitations in European refund strategies, it is possible that a certain portion of the population is excluded from potential refunds. This subset could be an opportunity for new business as these users currently may not be able to afford AT without financial help. Re-used products could be made available at a reduced price without leading to new product cannibalization.

An other opportunity lies in removing the distinction between new and re-used products by introducing them into the market as a service based model. This would increase the total amount of available products at a reduced cost. A possible reduction in sales due to a negative perception of reused devices could be counteracted by making refunds conditional to the re-usability of an AT device.

3 DISCUSSION

In the previous sections we notice certain conflicts in the described design methods. Modular design is suggested either to group components on a functional level (to increase adaptability to diverse and changing user requirements), or to group components according to expected lifespan (as an optimization strategy for disassembly), or to group components as individual products (to optimize the advantage from economy of scale). More research is needed to define which of these options will give the greatest economical benefit, while still fulfilling all stakeholders' requirements.
One factor that keeps returning when discussing AT is the lack of 'Economy of scale'. A potential solution for dealing with this issue is the use of mainstream 'off-the-shelf' products as components for AT devices. An example could be using mainstream tablet computers as processing units for communication aids. These mainstream products must be adapted to the needs of the target group of AT devices, for example by adding alternative input methods and sound amplification modules. It should however be noted that this modular design approach is to be considered in a trade-off between flexibility, cost, reliability and durability. A way of optimizing this trade-off could be to provide flexibility in the choice of components, but assembling these components in a robust and streamlined fashion, in analogy of the business PC concept.

4 CONCLUSION

A reasonable amount of research has been performed into the usefulness and feasibility of re-use. This research however does not take into account the smaller scale of AT due to the small target audience. The reported high rate of abandonment does lead us to believe there is a potential economic benefit from re-use within AT, however it is clear that more research must be performed analyzing this issue.
While incorporating re-use into the design methods seems mandatory to allow for an efficient re-use system, without a decent network managing the return, repair, and distribution of reusable products,

re-use will likely not be feasible. From a business perspective, academics state that the combination of re-manufacturing and products-service systems (where OEM retains ownership of their product) is the ideal model to ensure the efficiency of reverse flow logistics and encourages more design for re-use (Sundin & Bras, 2005; Östlin et al., 2009; Hatcher et al., 2011).

We conclude that re-use has the potential of leading to a reduced total governmental cost of providing AT applications. However, to ensure a minimal conflict of interest with AT providers, more research is needed analyzing possible regulatory influence and service delivery systems.

As future work we will use the issues discussed in this paper as input for selecting or defining design methods that can optimally facilitate re-use within the AT domain. It should be noted that, even when designing for optimal facilitation of re-use, design methods that facilitate the prevention of new AT should be prioritized. We will attempt to validate these methods through multiple case studies.

As an alternative to re-use in its traditional form, we wish to investigate the possibility of building AT devices using mainstream off-the-shelf components, that meet all the stakeholders' requirements, including durability and reliability.

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