VISION2REUSE

Best practice guide

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1. Background and importance

Reusable packaging is an important pillar in the strategy towards more circular packaging both at European, national and Flemish level. Within Europe, it is stated that by 2030 all packaging must be 100% recyclable or reusable. Fevia, the federation of the Belgian food industry, has set these targets even more sharply with a deadline by 2025. Several initiatives and projects are already in progress to increase the use of recyclable packaging.

To encourage the use of reusable packaging, many research and implementation questions still need to be answered, e.g. accurate and automated detection methods for defects and/or contamination. It is very important to ensure consumer safety as well as the economic feasibility of the business model. The **VISION2REUSE** project demonstrates the applicability of various smart cameras for automatic quality control (e.g. detection of scratches, tears, contamination) of reusable packaging in the food and packaging industry. The two-year project started on 1 January 2022 and received a grant of €324,422 from the European Regional Development Fund (ERDF).

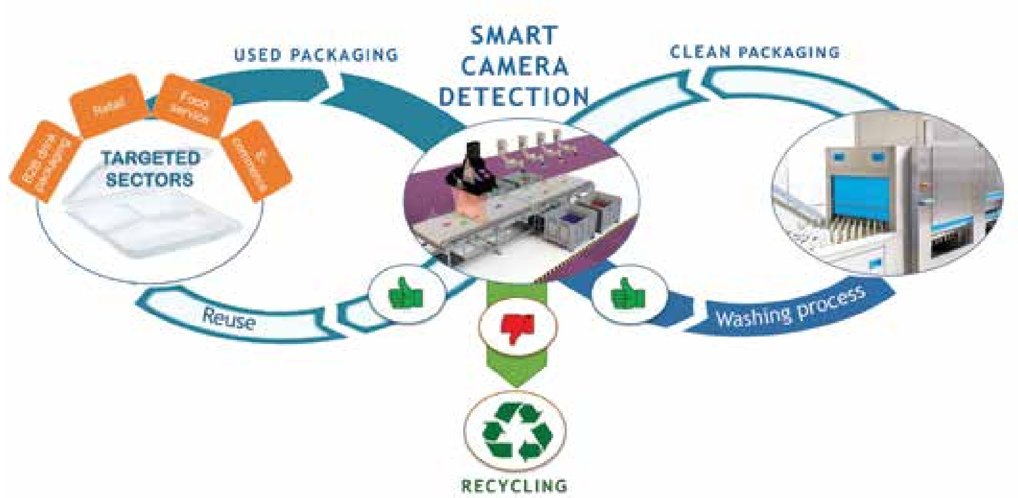


Figure 1/ Illustration showing where automatic quality control of reusable packaging can be deployed.

2. Relevance

In addition to the initiatives aimed at encouraging companies towards sustainable packaging, there is also legislation imposing stricter rules on packaging. Here, we provide an overview of the current legislation, proposals and initiatives to encourage companies to use sustainable packaging.

Legislation

- Single Use Plastics Directive (SUP-directive EU 2019/904): reduction of the impact of certain plastic products on the environment. Single-use food packaging incl. cups are part of the envisioned plastic objects.

10 MOST COMMON PLASTIC OBJECTS FOUND ON EUROPEAN BEACHS

Source: based on JRC report

- Packaging & Packaging Waste Regulation (PPWR, proposal November 2022) This is a thorough revision of the current Packaging and Packaging Waste Directive, from 1994. The main focus of this new regulation will be *reduce* - ***reuse*** - *recycle*. Recycle: all plastic packaging materials put on the European market should be 100% recyclable by 2030.

Flemish initiatives

- Green Deal Anders Verpakt, a Flemish framework for various European objectives. Focus is on prevention and reuse of packaging and reducing (excess) packaging & packaging waste. This is done through a chain approach: cooperation of companies, governments & knowledge institutions. Several companies have signed the charter to efficiently achieve the common objectives including pilot projects such as VISION2REUSE.

Economic opportunities

“Shifting just 20% of plastic packaging from single use to reuse is an innovation opportunity worth an estimated $10 billion upstream.”

source Ellen McArthur

The current linear economic model is reaching its limits and is not sustainable, both environmentally and economically. On the other hand, a circular economic model offers a framework for a thriving and resilient economy with lasting potential. Innovations in sustainability serve as a catalyst for growth and the generation of wealth.

Ambition:

“By 2030 and within a European framework, achieve and consolidate Belgian industry’s position as a leader in the circular economy.”

source FEB, Federation of Belgian Enterprises (VBO)

Belgium has the potential to lead the world in the development of materials, systems, processes and digital tools needed to realize this vision of reuse. Hence cooperation throughout the entire value chain is essential to seize these opportunities to make the necessary developments!

3. Partners & Roles: throughout the whole value chain

- **Flanders’ FOOD** is the Flemish spearhead cluster for the agri-food industry. This strategy-driven innovation platform stands for a more competitive, innovative and sustainable agri-food industry. Flanders’ FOOD strengthens the innovation force by increasing the scientific and technological knowledge and thus contributes to the economic and social development of Flanders. Flanders’ FOOD has members in the broad ecosystem of the food industry: in addition to members food companies technology providers (sensors and data processing) and coating companies are also members.

- **Pack4Food** is a consortium of industry and research partners throughout the whole value chain of food, packaging and packaging processes. Pack4Food offers support to companies in their daily packaging challenges and innovation processes by providing independent advice, training, initiating and participating in national and international research projects and last but not least, offering an international network to its members. Pack4Food coordinated the *Roadmap ‘Food packaging of the Future’*, in cooperation with the four spearhead clusters Flanders’ FOOD, VIL, Catalisti and SIM to set the vision of how food packaging should look like by 2030 and describes in four core themes which short, mid- and long-term research projects need to be set up to meet that vision. In the coming years this will be elaborated on a European level by the S3 platform for Food Packaging led by Pack4Food with support of Flanders’ FOOD. This VISION2REUSE project on re-usable packaging touches practically three core Roadmap themes i.e. sustainable food packaging, packaging and logistic processes and packaging and digitalisation.

- **Imec** is an independent research centre that specializes in nanoelectronics and digital technology. With over 4,500 employees and a global network of partners, including top scientists and experts, imec is the largest of its kind. Their research covers a wide range of areas, including semiconductor technology, smart healthcare solutions, sustainable energy and mobility, smart cities, artificial intelligence, 5G communication, computer vision, and advanced sensor technologies. In particular, they work with hyperspectral cameras for industrial inspection applications in both visible and near-infrared (VNIR) and short-wave infrared (SWIR) domains. Imec’s research and development capabilities are supported by funding from the Flemish and European Regional Development Funds.

Flanders’ FOOD, Pack4Food and Imec wish to thank everyone who directly or indirectly contributed to this project with special thanks to the supporting industry partners and independent observers Fevia, Fostplus and Valipac.

4.
How tackled in this project?

Why do we need automated vision inspection systems?

Currently the inspection of the reusable material is typically done visually by experienced workers. This inspection allows them to detect material with defects (stains, scratches, deformations…). The quality control process is therefore time-consuming, subjective and requires trained personnel.

While the human eye remains inherently more technologically advanced than any camera system, it is not without flaws. Manual inspection errors typically fall within the range of 20 to 30%. Various factors contribute to these errors, including fatigue, pressure, isolation, poor lighting, noise, and lack of experience. Such human errors can significantly affect overall performance, leading to avoidable costs. Furthermore, humans do not scale efficiently with the increasing number of inspections required for very large batches of reusable food packages, underscoring the limitations of manual inspection in handling extensive workloads. An automated vision inspection system can influence the performance of wash cycles (e.g., resulting in pre-sorting or adjusted washing parameters) and has thus the potential to have a significant impact on cost and environment.

Colour/RGB imaging acquires three broad spectral bands corresponding to the ranges of the electromagnetic spectrum which humans perceive as Red, Green and Blue (RGB). **Hyperspectral imaging subdivides these broad bands into many more narrow bands** and can potentially go beyond the visible light domain (400-750 nm) extending for instance to the infrared domain (750 nm – 1000 µm) or the ultra-violet range (10-400 nm). This greatly increases the amount of information from an image and provides for every pixel in the image a full spectrum, indicating how the light is reflected in the pixel for a range of wavelengths.

Hyperspectral imaging combines the characteristics of computer vision and point spectroscopy by obtaining an image with both spatial and spectral information. This enables therefore to analyse the chemical composition of materials and simultaneously visualize their spatial distribution. This combined spatial and spectral information of hyperspectral image data can be perceived as a three-dimensional data cube, where every two-dimensional band image provides information about a specific reflected band. This is illustrated in Figure 2.

Camera sensors

Many types of different camera sensors exist. One way to classify the different sensors is to look at their sensitivity in the different parts of the electromagnetic spectrum. We, humans, can only observe the so-called visual part of the spectrum (which ranges roughly from 400 to 700 nm). Computers and cameras are not restricted to this range and can observe a much wider range: from gamma rays, x-rays and ultraviolet (with shorter wavelengths) to infrared, microwaves and radio waves (with longer wavelengths).

Most interesting spectra for inspecting reusable food packages are located in the **ultraviolet, visual and infrared** ranges (which includes thermal imaging). Since materials have specific spectral reflectance signatures, using bare or monochrome sensors without filters will only give information about high and low intensity signals and thus makes it harder to distinguish materials based on reflectance only. Therefore, passband filters will help to discriminate the spectral features: e.g., relative broadband filters for red-green-blue (and near-infrared in case of multispectral systems) or very narrowband filters for hyperspectral systems.

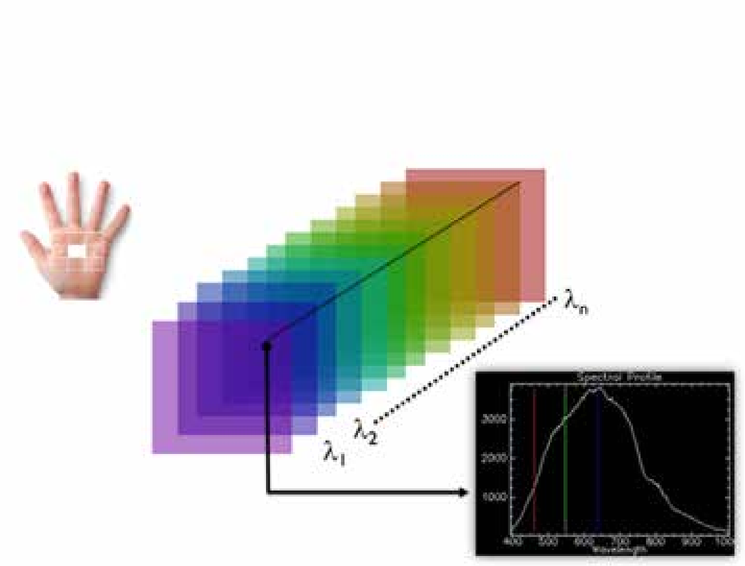


Figure 2/ In hyperspectral imaging, n different band images are acquired, such that for every pixel in the image a spectrum is obtained.

How to choose the right camera sensor?

The choice will largely depend on the **application and technology requirements**: one needs to find out which vision problem(s) need to be tackled. Beware that attaining a very high performance also increases either the cost or complexity of the imaging system in general. *For example, the same problem could perhaps be solved using multiple (cheaper) cameras instead of one, slightly increasing the complexity.*

Next to that a **trade-off in resolution** has to be made in the spatial, temporal and spectral axes. The *spatial resolution* is defined by the combination of the number of pixels and the appropriate choice of the lens, which is then also related to the field of view. The *temporal resolution* is characterized by the frame rate that a camera can capture, which can be crucial in dynamic scenes (e.g., on a conveyor belt). The *spectral resolution* is related to the discrimination power (e.g., a spectrometer can measure only one point but with highest spectral resolution, while on the other side, a monochrome camera cannot discriminate the different materials well). RGB and hyperspectral cameras make a trade-off in these four axes as illustrated below.

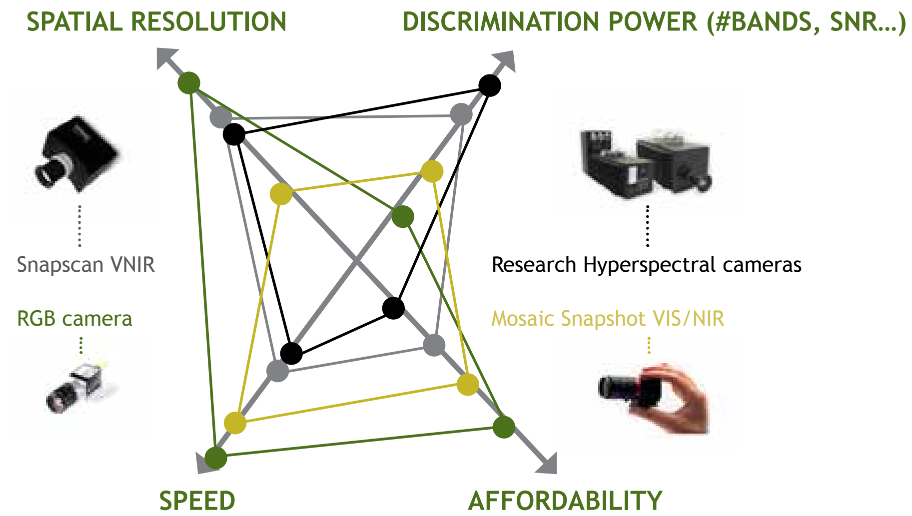


Figure 3/ Schematic illustration of the hyperspectral camera trade-offs in VNIR range.

Imaging

What a camera sensor observes is actually how light interacts with the material. Therefore, the **light source** is a very important aspect of an imaging system, especially for obtaining good quality images. If one relies on the ambient light, the imaging system is passive (and thus less controlled). On the other hand, an active imaging system assures the same light conditions over time and typically results in better image quality (e.g., less noise). In general, the packaging or sample absorbs some light (depending on the absorption spectrum of the material), some light is bounced off on the surface (either the light is directly reflected or scattered) and some light is transmitted through the object. Note that this *transparency* is different at different wavelengths, again depending on the absorption spectrum. For now we discard phenomena such as fluorescence. These physical principles poses several constraints on imaging which leads to several imaging challenges, for example:

- In case the sensor captures reflected light from objects with dark colours such as black: the material will absorbs most light and only little light is captured by the camera. This typically results in low signal to noise ratio. A more powerful light source can decrease the noise and low reflectance in the visual part of the spectrum does not necessarily mean low reflectance in other spectral parts such as infrared.
- Highly reflective material (e.g., steel) typically cause specular reflections resulting in saturated blobs where information is completely lost. Making the light source diffuse will largely mitigate this problem.
- Performing visual inspection of transparent material can be done by either capturing the transmitted light (i.e., placing the object between the light source and the camera, and thus requires a different camera setup) or analysing the reflected light that passes the object twice and which is bounced off the background. In the latter case, the background will have a major impact for the subsequent image analysis.

Lights, camera, action!

Much like cinematography, light sources are crucial in automated visual inspection systems. The illumination system must be carefully designed with the camera system for optimal image quality, considering key aspects:

- **Light intensity**: The rule is simple – *more light, less noise*. However, limitations exist due to factors like energy consumption and eye safety. Furthermore, trade-offs must be made on sensor size (larger sensors suffer less from noise but are more expensive), on exposure time (large exposure times deliver higher image quality under low-light conditions, but also lower the framerate and are prone to motion blur), on optical filters (RGB filters allow more light than hyperspectral ones, but have a lower discrimination power).
- **Spectral distribution**: different light sources (e.g., sun, LED, halogen, etc.) emit varied spectra. It is important to choose a light source that can emit continuously and with sufficient power over the wavelength range that we wish to measure with the sensor. Moreover, equal energy distribution is essential to achieve a more balanced signal to noise ratio. If not, it could lead to very poor image quality with over- and underexposures in image bands captured at different wavelengths.
- **Spatial distribution**: ideally we achieve a homogeneous spatial distribution of light energy, i.e. the incident light should have the same spectral response and intensity at each position of the field of view. Furthermore, shadows and specular reflections should be avoided. Diffusers, polarized filters and multiple well-positioned light sources enhance the homogeneity.
- **Temporal distribution**: ideally the light source remains stable and emits the same light energy over time. Sunlight for example may fluctuate over time, especially with clouds. Although we are focusing on indoor visual inspection applications, the ambient light can largely be impacted by the sun through windows. Mitigation involves employing an imaging box for control, or compensating variations with auto-exposure algorithms or incident light sensor measurements, at the expense of adding an extra layer of complexity to the system.

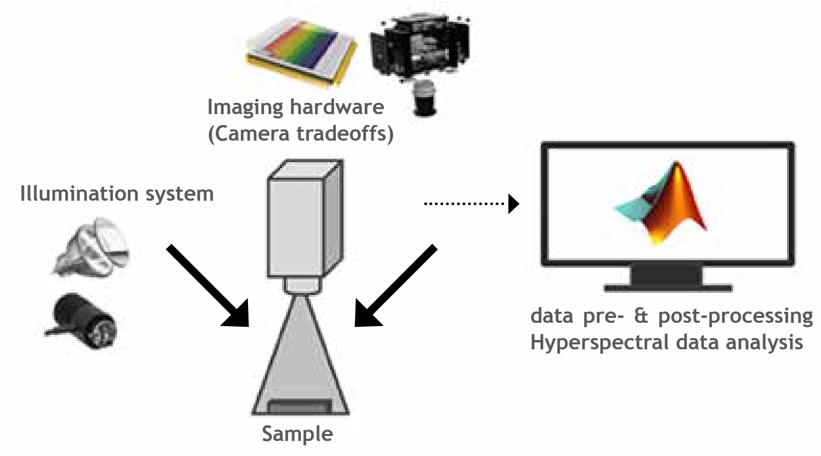


Figure 4/ Main system parameters of a hyperspectral/colour camera system

Computer vision

Given a camera and a computer, which information on reusable food packaging and on defects/impurities can we extract from the image(s)? Looking at each individual pixels we can extract **spectral information**. After proper calibration, we can obtain reflectance (in case of hyperspectral) or colorimetric information (in case of RGB). Complete reflectance models can be related to materials. Furthermore, we can derive **spatial information** such as texture or shapes. Using (active or passive) depth imaging, we can even obtain the complete 3D geometry of the objects. Finally, **high-level meta information** can be extracted from images using deep neural networks. Especially, the rapid progress of large foundation models is ushering in a new era of advanced and versatile AI-driven solutions.

How to present the sample?

The way a sample is presented to the camera system, for instance in terms of background choice, can have a considerable impact on the system performance. Despite the relevance of background choice as a mean to increase discrimination when samples are for instance translucent or in general to help avoid shades or specular effects, very few works exist in literature focusing on these aspects. When the sample itself is glossy or specular, we can partially deal with this by a careful choice of the illumination system and optical components.

- **Impact of background material**: this is mainly relevant for transparent materials, but it can partly also impact inspection of opaque materials. With colour imaging and human vision, the appearance of any transparent material is going to be affected by the background colour/material behind/underneath it. Therefore, this impacts the acquired image for both colour imaging systems and hyperspectral systems. The reason is that the light traverses the transparent material and is then reflected by the background traversing again our transparent material, and only then reaches our image sensor with an impact from both background and transparent object. In the case of colour imaging this is perceived as an impact of the background colour on the transparent material. In the case of spectral imaging, a mix of the spectral signature of background material and transparent one happens. This means that the perceived spectra of any given transparent material will depend on the background underneath. While some background spectra may ease discrimination of a specific defect or material spectra, other background type may interfere or reduce the discrimination on the transparent object of interest.
- **Potential interferences in detection/discrimination accuracy** In this respect, if inspection happens at either input/output of a washing tunnel a specific background or inspection setup might be in place. In some washing tunnels the cups/containers may be placed on fingers while on others they can be placed on a tray (see Figure 5). Both fingers and underlying tray will be partially seen through transparent material, which means the resulting object spectral signature/colour could be impacted. Therefore, this must be considered during the training phase of the detection/classification algorithms. Failing to capture the real setup conditions during the training phase would compromise the system performance under realistic conditions.

Figure 5/ Reusable cups being placed on tray or on fingers.

Similarly, the presence of dirt or water on a container could somehow interfere with the detection of specific defects or even material detection. To interfere with material detection the dirt coverage would need to be covering most of the sample and probably thicker than a millimetre. In practice we have not met this type of situation, and small presence of lime or remaining dirt did not interfere.

- **Impact of edges** Edges in the container/material are always more difficult to inspect, since typically more specularities and anormal light reflections happen at these areas. For instance, a round container with less edges would be easier to inspect than a square container. Specular effects occur and this is particularly the case for plastic or glass containers with a smooth surface. A specular effect will translate typically in an area where the cameras detect signal saturation level. Meaningful spectra at these areas cannot be recovered and typically saturated areas are easily detected and discarded from the analysis. Usually only a small fraction of the whole container is affected by specularities (e.g. 5%), therefore it does not compromise material identification or defect detection for the full container. However, in the small area where the specularity or edge happens, a small defect could be missed. A solution for this could be to perform more than one measurement and change the object position/angle. This will vary the specular location and allow inspection of all areas.

Seamless systems, integrated solutions.

So far, lights and camera sensors constitute a significant part of an automated vision inspection systems, but we still need to take into account many other factors, for example:

- Often, the application space is confined or restricted. This has an impact on the lens selection to have a proper focus and resolution, which are determined by the working distance, the field of view and the depth-of-field.
- Camera systems have to be calibrated. Camera parameters have to be adjusted well, for example, the exposure triangle: aperture, ISO and shutter speed. Furthermore, image compression might have to be applied (for storage or network transmission) or the analysis could perhaps even be performed on the edge.
- There might be constraints on the camera body: the camera could be industrial grade to work in tough environments (think for example of steam in washing streets) or the camera should be compact and lightweight to be mounted on robotic arms.
- Inspection might have to be performed from multiple angles and positions, avoiding blind spots and (self-)occlusions.
- Feedback and control are needed to (semi-)automatically remove defect or dirty packages from the line: this can be implemented mechanically or operators can receive feedback through augmented reality (for example, indicated by coloured lights).

System integrators bring together different subsystems (both hardware and software) into a single integrated and customized solution and ensure that they function in tandem with one. Therefore, they should be involved in setting up the application and technology requirements.

Image analysis

Classical image analysis consists of two steps: 1) feature extraction and 2) a decision rule to classify the reusable food packages (e.g., answering the question "Can we reuse this food package?" with a simple yes or no). The complexity of features ranges from very simple (e.g., pixels colours, spectra, corners, etc.) to very complex (e.g., object templates, shape or texture descriptors in transformed domains). The decision rule can be detectors derived from hypothesis testing (thresholding) or can even be trained with a provided set of labelled data (now we have entered the domain of machine learning). With the advance of computational power and the increasing amount of (labelled) data, image analysis can train both the features and decision rule in one go, typically done in an end-to-end artificial deep neural network. Although AI models are very popular nowadays, they still suffer from several limitations and disadvantages such as high cost, need for large datasets, etc.

One method to rule them all?

Before directly jumping into AI models, we have to ask ourselves: Can we solve the problem with much simpler and cost-effective methods? In some cases we can indeed use relative simple methods:

› Material classification: the spectra for different plastics (e.g., PC, PE, PP, PET, etc.) are very much different in the short-wave infrared (SWIR) range and the classification can be done with standard classifiers such as spectral angle mapper per pixel or per segment.
› Water detection: water absorbs infrared light at a wavelength range from 1,450-1,500nm, which results in black and opaque segments in hyperspectral SWIR imagery that can easily be detected with standard classifiers.
› 3D defects (e.g., cracks, deformation): given aligned 3D models of an ideal package and observed package, we can easily calculate local and global deviations.

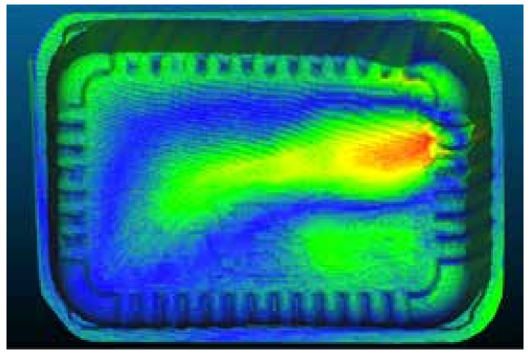


Figure 6/ Illustration of a 3D model from a food container: the colour scale ranges from blue (no defect) to red (large deviations)

We can enhance the performance of these methods with AI-based models, but there are some drawbacks to consider. For instance, the complexity of implementing and maintaining such models poses a challenge. Despite the potential benefits, a thoughtful approach is crucial to mitigate the associated challenges. Some challenges are listed below:

› How do we obtain large, labelled datasets? This would preferably be obtained without too much human intervention.
› How do we obtain balanced datasets (i.e., enough samples from each class)? This is especially a challenge for rare defects.
› How can we trust and explain the results of the AI-based models? Furthermore, how can we correct the AI-model for future mistakes?
› How can the AI models be transferred between different imaging setups or how can they cope with new food packages?
› How can we limit the need for substantial computational resources that may arise, which also leads to increased costs?
› …

Unfortunately, there is no *free lunch*, meaning that there is no single best (optimization) algorithm. Although in the box below we will motivate our choices with respect to the inspection of reusable food packages provided within the project.

Anomaly detection and training strategies

The main goal within VISION2REUSE project was to build a generic deep learning framework that allows for an easy-to-train setup and the flexibility to accept new packaging. We opted for an anomaly detection framework, which is a (convolutional) neural network with an encoder part that projects the input into a lower dimensional latent space (or manifold) and a decoder part that projects these features back to the observation space. An anomaly is an outlier that is not well reconstructed by the network (either in feature space or in image space).

Anomaly detection has several key benefits:

› Only a few samples are needed to train the neural network. Consequently, this allows a rapid setup for new types of packaging.
› This approach can cope with un(fore)seen defects which makes the system very robust. The system should be resilient to new trends such as blue lipstick marks on reusable cups.
› The decoder part adds the possibility for visualization and localization of the detected defects, which then can further be interpreted by the operator.
› This concept allows us to study different problems such as discoloration (the manifold will represent a colour palette of acceptable package colours), defect detection such as scratches and deformations (the manifold will only contain information about acceptable shapes) or contamination detection such as mould and stains (the manifold will only represent colours, texture and other local material characteristics of an ideal package).

Furthermore, we proposed a combination of advanced training strategies (i.e., distillation training, combining the best of semi-supervised and supervised learning) that add more advantages to the AI-based approach:

› High-quality reconstruction can be obtained by larger image datasets, this knowledge can be transferred to the anomaly detection framework.
› Small neural networks can be inferred through teacher-student training, which can then be deployed on embedded systems and reduce the computational costs and energy.
› The system allows for perpetual training and the flexibility for new packaging (knowledge on defects gathered other packages can be transferred).

CONCLUSIONS

For general scratches and deformation defects, colour imaging is a more suitable technology since it provides higher spatial resolution to detect small scratches. In addition, these types of defects are more linked to spatial feature (texture, geometry) … Therefore not so related to spectral information and hyperspectral imaging.

For mould detection both hyperspectral and colour imaging could detect the presence of these small dots-alike stains. However, there was not really a need to identify whether a small stain could be mould or something else since in any case both types of defects would be rejected from consumer's use perspective. Some discoloration defects of container could be slightly better perceived with hyperspectral imaging than with colour imaging. However, these defects only pose problems when they can be already visually perceived by the human eye, and therefore colour imaging would be sufficient. As a rule of thumb, whatever can be perceived by the human eye, can be detected as well with colour imaging and does not require hyperspectral imaging per se.

For material discrimination or water detection hyperspectral imaging has a clear added value with respect to colour imaging since colour imaging cannot provide material discrimination and it is difficult to visualize water presence, therefor hyperspectral imaging is a better alternative for these two cases.

Unlocking new possibilities…

Design for X

With the variety of reusable food packages we have encountered in this project, we noticed that these existing packages were not necessarily designed for inspection. Therefore, the ideal package for inspection could lower the complexity and cost of the automated vision inspection systems. Of course, this design principle can be applied in general on many aspects such as manufacturability, cost, logistics, ergonomics, aesthetics, etc. Addressing the different design guidelines to create the "perfect" package is an exercise that can only be solved jointly by all involved stakeholders.

User requirements

Besides application and technology requirements, user requirements are also needed to pose the right questions, for example: what is acceptable and what is not acceptable to reuse? The answer might change depending on the target group, but will have an impact on setting up the hyperparameters of the AI models. Furthermore, the expected answer might not be binary but rather quality labels. Food safety is also an important factor: is the package clean enough if we or the camera sensor cannot see it in the visual spectrum? Finding an answer on these questions requires new multidisciplinary studies.

5. Camera systems trade-offs

The main characteristics of the hyperspectral imaging cameras is provided in Table 1.

HSI CAMERA	# BANDS	SPATIAL RESOLUTION	COST	SIZE/WEIGHT
Illumination setup (halogen/LED) and lenses	-	-	€	
Snapscan VNIR (460-900 nm)	150	3000x2048 px	€€	10x7x7 cm/645 g
Mosaic VIS (460-600 nm)	16	512 x256 px	€€	26x26x31mm/ 32 g
Mosaic RedNIR (600-850 nm)	16	512 x256 px	€€	26x26x31mm/ 32 g
Mosaic NIR (670-950 nm)	25	409 x 217 px	€€	26x26x31mm/ 32 g
Snapscan SWIR (1100-1650nm)	100	1200 x 540 px	€€€	9x9x13 cm / 1072 g
Mosaic SWIR (1100-1650nm)	9	211 x 168 px	€€€	65x65x130mm/260 g

Table 1/ Summary of imec hyperspectral camera systems characteristics

Prices of the camera systems, illumination setup (both halogen and LED) are available upon request.

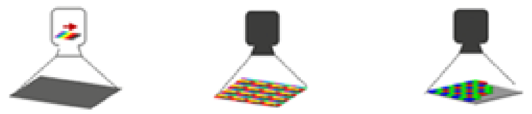
Acquiring the spectrum or spectral signature for every pixel in the image has the potential to greatly increase the material information and discrimination capabilities with respect to traditional RGB machine vision. Imec hyperspectral technology offers two type of sensor systems:

- **Line-scan hyperspectral imager**: with a novel camera system, Snapscan, where scanning is handled internally.
- **Mosaic snapshot imager**: in this sensor, the filters are arranged onto individual pixels building a mosaic pattern.

Generally, scanning acquisition systems such as **line-scan/Snapscan systems can obtain hyperspectral images with high spectral and spatial resolution**, but require time for the scanning. In contrast, **snapshot systems trade-off between spectral and spatial resolution to be able to provide instantaneous and faster acquisition** than

scanning systems. Both Snapscan and Snapshot (Mosaic) concepts are available in the visual near-infrared (460-900 nm, VNIR) and the short-wave infrared (SWIR) range between 1100 and 1650 nm.

Figure 7/ Visualization of spatial-spectral trade-offs for camera systems



	SNAPSCAN	SNAPSHOT MOSAIC	RGB
Acquisition speed	+	+++	+++
Video rate	-	+++	+++
Spacial resolution (max.)	+++	+	+++
Spectral resolution	+++	++	-
SNR	+++	+	+++
KEY PROS	Highest quality cubes being 'snapshot' + no 3D topography issue	True snapshot @video rate	High spacial resolution @video rate
KEY CONS	video rate not in reach	SW corrections needed for crosstalk	No spectral resolution at all

Table 2/ Visualization of camera system trade-offs

High resolution hyperspectral cameras with 100's of bands capture very detailed spectral information of the materials/objects and at higher spatial resolution. However, this translates as well into **high memory and data processing requirements**. For this reason, **it is advisable to perform a band relevance analysis** to extract the most relevant bands. Typically, **some performance trade-off in terms of accuracy versus number of bands used**, is expected but a subset of bands will very likely meet the application requirements. The use of a lower set of bands, such as with snapshot cameras, will reduce memory and data processing, while increase the acquisition speed.

The identified set of relevant bands can also steer future development of **quantum-dot based cameras**. This new technology has the potential for **lower cost and higher spatial resolution** cameras than current InGaAs SWIR cameras. Future developments will allow these sensors to measure a few selected spectral bands, paving the way for low cost and high spatial resolution spectral QD sensors.

6. Design4Reuse Guidelines
Key lessons learned based on AMAB's experience

As of 2020, the use of reusable drinking cups at public events is virtually mandatory in Belgium. Once used, these reusable cups will be washed in most cases by social enterprises specialised in customised work. The WASH-IT consortium (www.wash-it.be) combines various social enterprise partners like AMAB, both are partner in the VISION2REUSE project. AMAB shared their insights based on four years of experience. Doing this they hope to stimulate the use of reusable packaging and wash cups, catering materials and other food packages more effectively and efficiently the future. These guidelines are to be considered as high-level considerations and recommendations and do not intend to set technical standards but merely to support developing re-use solutions.

The washing process of AMAB's washing tunnel (MEIKO) is determined by 4 parameters:

› **Mechanics**: construction of the machine, e.g. AMAB's professional washing tunnel (MEIKO) has 4 drying zones for drying plastic and 1 pre-wash zone
› **Chemistry**: quantity and type of detergents
› **Temperature**: the temperature settings in the 4 different zones of the washing tunnel at AMAB:
  - Pre-wash zone: around 55°C
  - Washing zone: around 60°C
  - Rinsing zone: around 80°C
  - Drying zones: around 75°C to 80°C
› **Contact time of water and detergent** with the cup or packaging. At AMAB this is 1.5 meters/min (or slower) when washed according to the standard DIN SPEC 10534 for Food hygiene - Commercial dishwashing - Hygiene requirements testing.
  - *DIN SPEC 10534 is a standard is for cleaning wash ware that is used in contact with food, such as e. g. tableware, glassware, cutlery, reusable boxes and similar articles in commercial wash tunnels as used in kitchens e. g. in restaurants, canteens and hospitals and in commercial enterprises such as e. g. bakeries, butcher's shops, etc. It describes the methods for testing hygienic operation. It also specifies principles for proper spatial and functional arrangements within the kitchen area and for proper and hygienic organization of the wash ware cycle*

Experience in washing different plastic cup materials

Preference is given to PP rather than PC for plastics.

Both polypropylene (PP) and polycarbonate (PC) cups are currently on the market and used on events. However, PP provides the least problems in terms of temperature sensitivity and detergent settings. Also, PC despite its high transparency (glass look alike), is very scratch-sensitive and is quickly damaged because cups are often stacked or nested to optimize their space usage during transport.

An explanation can be found in the performance characteristics of the materials.

PP is a crystalline thermoplastic polymer with a melting temperature (Tm)[1] between 130 to 171 °C (depending on if homo- or co-polymer). PP cups or packages are very rigid, strong and have a high impact resistance.

PC is an amorphous thermoplastic polymer and the glass transition temperature (Tg)[2] for PC is around 150 to 160°C (PP Tg is around -20 to -10°C).

Tritan© is another cup material with a good Tg (110°C) that can be found on the market but is very scratch sensitive like PC and therefore not favourable for many re-usages in a professional environment. On top, this material is only recyclable if it is returned to Eastman Company.

Historically the detergent formulations for professional washing machines are developed for cleaning porcelain and glass. Today more special detergents specifically for plastics are in the process of being developed but until then the process settings with current detergents (temperature, time and amount of water) are set on a basis of own experience. Also, during the drying process, the finger-rests onto which the cups or recipients are placed, vibrate to support the formation and removal of droplets of the cup surface to fasten the drying process. This vibration frequency also depends on the cup or recipient material.

As cups coming from events can be provided by several suppliers, the materials of the cups going into the washing tunnel are in many cases a mix of PP or PC. Consequently, the washing process settings are a balance and set on the average best cleaning of the mix of cup materials.

'To improve the efficiency and effectiveness of the washing process performance, it would be ideal to only have **one type of cup or recipient material**. Based on current experience **with plastics, preference is given to PP**.'

1 The melting temperature (Tm) determines the temperature at which it melts.

2 Glass transition temperature (Tg) determines the thermal stability and flexibility.

What about polyethylene terephthalate (PET) or poly lactic acid (PLA) as reusable cup materials? An hygienic professional washing process for food recipients or cups requests a minimum washing temperature between 70 to 80°C. As for PET (polyethylene terephthalate), despite its many advantages for food packages like being strong and lightweighted, its Tg is around 70-80°C and for PLA (poly lactic acid) the Tg is around 50-60°C.

Hence, **cups in PET or PLA deform at the high washing process temperatures and are not suitable**. This is why there are no re-usable cups in this material on the market for large professional events.

Experience in washing different cup shapes/designs

The design and surface finish of the cups or food recipients may even play a bigger role than the material itself because of how a professional washing tunnel washes the recipients.

The design and surface finish should be as smooth as possible and have no undercuts nor indents as this creates a high risk for water retention. An example is the dimple or little dent in the base of a champagne glass.

First, in the washing zones, the water and detergents from the washing arms above and under the cups or recipients should easily reach all areas to enable and ensure perfect cleaning.

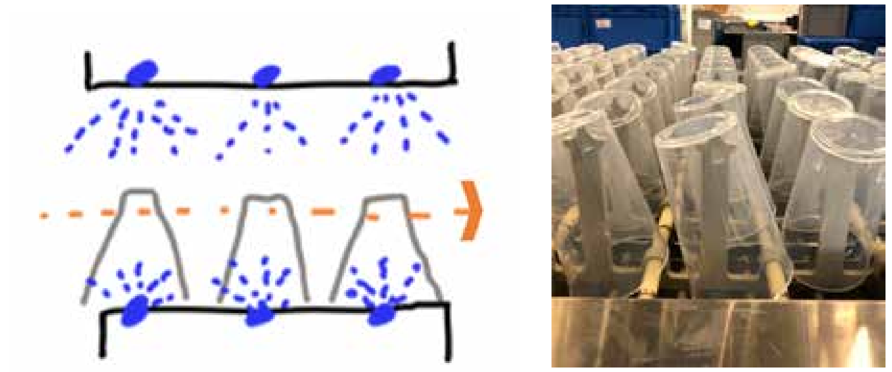


Figure 8/ Position of cups on finger-rest system

Second, in the drying zone, the blowers with heated air should be able to dry the in and outside surface of the cleaned cups or recipients. If water remains behind e.g. in a notch or dent, the blowers incl. vibration cannot remove it in due time. Afterwards, if not perfectly dried, the moisture will stay in between e.g. the cups when stacked in tubes or sleeves. This is problematic in terms of food safety and hygiene since this can be a source of mould growth and/or growth of other micro-organisms. Therefore, the design of a cup or food recipient must be optimized for perfect cleaning, drying & storage (i.e. nested storage).

'**Hygienic designs** for re-usable packing systems as well for solid as liquid food products are imperative to make re-usable packaging systems viable.'

Sorting of cups or food recipients

The terms of delivery of cups to be cleaned by AMAB, there is ideally one cup type per box. The warehouse operator records the type and the incoming number of cups in the ERP system so the washing team knows what to expect. Sorting of cups is necessary when putting them in the supply area of the washing tunnel and setting the washing process parameters (see also impact of cup materials on the washing process). AMAB's washing tunnel has eight rows of fingers where they can mix maximum two types of cups. The first four rows can be occupied with one type and the other four rows with the other type of cups. In this way, the cups are removed from the belt by type and can follow the respective stacking schedule as well as bringing them back to the right owner.

Dirty cups normally also arrive in tubes (for optimal storage). When they are heavily soiled, this sometimes causes problems in detaching them from each other on top of potentially scratching the surface of the cups. With additional sensibilization of the cup suppliers towards the stacking methods of the cup, this has decreased versus two years ago.

'Clear **stacking instructions** for incoming and outgoing cups or recipients are needed to minimize extra storage and sorting efforts and will allow a more efficient workflow.'

Figure 9/ Sleeve formation of cups for final storage

Screening for defects or contamination

There is a "breakage bin" where abnormal deformed or defected cups are collected. At the entry zone of the washing tunnel, all cups or recipients are manually checked and removed from the flow if there is an obvious defect and put in a waste bin, on top of a final manual check at the exit of the washing tunnel. Today, these checks are done 100% manually, future vision systems could support in these checks to improve to a more efficient workflow.

Further developments needed to improve the washing cycle performance

Standardized packaging to optimize the washing process. Now there is too much diversity in packaging (materials and designs), resulting in different washing and stacking schemes.

''Industry standards" are necessary for an efficient supply chain, facilitating widespread adaptation and sharing investments or costs. More standardized packages would also mean cleaning and working more efficiently.'

Figure 10/ Catering materials with special shapes gives difficulty when placed on the finger system.

Standardized quality guidelines for cleaning reusable packaging. What is OK and NOK needs to be clearly described by objective parameters, only then an e.g. vision system can be used optimally (specification limits, what is acceptable or not). Next to the hygienic needs, more information is needed on acceptability of e.g. brand visibility, deformation (e.g. ovality of cups), etc. This can be defined based on consumer or customer research.

Ideally, these vision systems would also be extended with e.g. a counting functionality and possibly also a link to guarantee transactions. E.g. end users get their deposit back when their their packaging or beaker has passed through the washing tunnel.

'Clear acceptability guidelines to analyse re-usable packaging defects will allow a more efficient workflow.'

7. Other developments needed across the entire (international) value chain

Sustainable, cross-sectoral partnerships are crucial for realizing the challenging logistical and economic solutions of reusable packaging systems. This can be stimulated and supported through:

› Cooperation of companies throughout the entire food/packaging/logistics value chain to develop and implement the technologies or solutions
› Identifying possible synergies between food and packaging companies and other relevant partners
› Communication and information to consumers as partners in the value chain (consumer attitudes and behaviour towards reusable packaging)

A profitable and sustainable* value chain will also need to include **reverse logistic systems**: *(sustainable*: i.e. balance between Profit, People & Planet)*

› **Scale** is of great importance; volumes of reusable packaging must be sufficiently large and preferably cross-chain (usable by all stakeholders), ideally both nationally and internationally
  - Social enterprises for customize work as well as co-packers/co-manufacturers can play an important role in this new ecosystem for re-usable packaging
› Development of **deposit or collection systems** that are consumer-friendly, sustainable and hygienic and development of relevant incentives to return packaging (e.g. deposit or reward system)

Some examples of current reusable packaging systems and platforms

› Euro Pool System | Duurzame plastic verpakking

› Loop - A Global Platform for Reuse (exploreloop.com)

› Swapbox - offers washing service, packaging rental and tracking technology solutions and is partner in Vision2Reuse

› Reloop Platform - Working on building a world free of waste

8. Interviews Stakeholders

alberts

What does your company do, and why were you interested in participating in this project?

Cilia Van Vaerenbergh: Alberts has developed a healthy vending machine that offers fresh snacks. The machine can prepare smoothies, soups, and plant-based shakes using frozen fruits and vegetables, with only water added. Our company is committed to sustainability, and we have already taken steps to reduce our single-use packaging. Our interest in this project is twofold: first, due to the food safety requirements for reusable packaging, and second, to explore the possibilities offered by smart cameras.

How has your participation in this project positively impacted your organization?

Firstly, we've gained insight into the significant potential of smart cameras. However, further development is needed, specifically in terms of specificity and sensitivity for different applications. Secondly, it has led to valuable brainstorming sessions with other stakeholders regarding reusable packaging, providing insight into the complexity of the subject.

Do you currently offer reusable cups?

We can offer different types of cups (packaging). We have transitioned from plastic cups to bagasse and now paper cups (with 0% plastic residue). Additionally, we can provide reusable plastic cups for use in the machine. However, these reusable cups need to be collected, cleaned, and refilled, posing a logistical challenge for our customers. To address this issue, we are exploring collaborations with service providers who can manage the logistics of reusable packaging, as we do believe reusable packaging is the way forward.

AMAB

What is your company's primary focus, and what motivated your participation in this project?

Lars Dedobbeleer: AMAB is a custom manufacturing company primarily specializing in packaging work, particularly in secondary and tertiary packaging. Since 2019, we've also established a dedicated washing facility for reusable cups. With our commitment to contributing to a circular economy, we joined this project to enhance our involvement in reusable packaging.

How has your involvement in this project benefited your organization?

The project has primarily enriched AMAB's knowledge in vision systems and best practices, such as "design for inspection." Currently, these aspects are in the exploratory phase, but our aim is to develop a standardized solution and achieve consensus within the industry.

How does AMAB currently ensure food safety and hygiene for reusable packaging?

We ensure food safety and hygiene in accordance with the DIN SPEC 10534 standard, adhering to stringent parameters, including contact time, temperature, and detergent dosage. Additionally, we conduct a manual final inspection at the end of our washing process. Here, we see opportunities for smart camera systems, as well as for counting and recording the number of packages.

What is the cost-effectiveness of utilizing tunnel washing services for reusable packaging compared to single-use alternatives?

Cost-effectiveness varies depending on the application and the use of potential deposit systems. On average, cleaning costs are approximately 10 cents per package, but the total expenses fluctuate depending on the quantity. Additionally, factors like procurement and transportation should be taken into account.

Does AMAB have any recommendations for companies exploring reusable packaging solutions?

My primary recommendation is to engage in dialogue. By collaborating with all stakeholders, it becomes possible to develop packaging that is easier to clean, resulting in reduced wastage and lower costs.

What is your company's primary focus, and what motivated your participation in this project?

Dieter Van Biesen: Red-use has a mission to replace single-use packaging with reusable materials. We serve three markets: events, the on-the-go market, and businesses. This project is crucial for us because it offers the possibility to automate the final part of the washing process. Currently, human control is essential there, but if we can partially automate it with technology, it provides more certainty.

How does your company ensure the food safety and hygiene of reusable packaging?

We work closely with suppliers of biodegradable cleaning products, such as Ecolab. Additionally, we have partnerships with machine suppliers. While there are no specific standards, we rely on our knowledge of packaging for unpackaged food and strive to align with standards like BRC and IFS.

What challenges does your company face with reusable packaging?

The biggest challenges are dependence on human control, logistics, and inadequate regulations. Control processes are labour-intensive, logistics need to be efficient, and regulations need to encourage sustainability. Legislation has been introduced for events, and reusable cups have become commonplace, with most people not thinking twice about it. I hope this project is not the end but a beginning.

What is your company's primary focus, and what motivated your participation in this project?

Tom De Vlaminck: Avamoplast is a family-owned business that manufactures reusable packaging solutions for the food industry. We joined this project in response to an increasing demand from our customers for reusable packaging, recognizing the absence of concrete solutions in the market. Additionally, we are working on a reusable pizza box and aim to ensure its quality post-cleaning.

How has your involvement in this project benefited your organization?

The most significant takeaway from our participation is the recognition that controlling the quality of reusable packaging is a complex endeavour, requiring various systems. These systems address both visible and non-visible aspects. Furthermore, we've gained valuable design guidelines, such as the challenges associated with detecting black or transparent packaging.

In your opinion, what is the most significant challenge regarding reusable packaging?

According to us, the primary challenge lies in legislation. There is a need for established norms that packaging must meet to qualify for reuse. The second challenge pertains to the logistics aspect. It involves determining how used packaging returns from consumers to the system for cleaning and refilling. This necessitates regulatory frameworks, and we believe the government should make informed decisions based on input from the industry, as seen in initiatives like VISION2REUSE, where industry stakeholders are engaged.

Fevia

What is Fevia's current vision regarding reusable packaging?

Candice Joseph: Fevia has been actively engaged in packaging matters for the past 20 years and has launched a sustainability strategy that includes a focus on sustainable packaging, including reusable packaging. Fevia, together with Comeos, Detic, Buurtsuper, and Unizo, has committed to bringing 100% circular packaging to the market by 2025. This implies that the packaging must be recyclable, reusable, or compostable, and it's crucial to assess the most suitable solution for each specific application.

What is Fevia's perspective on the role of regulations and policies in promoting reusable packaging in the food industry?

Regulations play a vital role in providing a framework, particularly concerning hygiene and safety standards, which are currently lacking in many cases. Defining responsibilities, such as ownership and hygiene, is of utmost importance, and it is essential to consider various approaches for different situations. We anticipate that the PPWR (European legislation) will have a significant impact on the use of reusable packaging.

What challenges does Fevia identify for the food industry when implementing reusable packaging?

Apart from addressing hygiene and food safety, it will be crucial to carefully assess the environmental impact and compare it to current packaging solutions to ensure that the alternative does not lead to increased food waste and other undesirable consequences. In the upcoming years, scaling up will be essential, achieved through a broader offering of reusable packaging and washing facilities, similar to the existing scale of single-use packaging. Notably, the food industry predominantly comprises small and medium-sized enterprises (SMEs) that may lack the necessary space, budget, or workforce. Implementing a "packaging-as-a-service" system can offer a solution for these SMEs to facilitate the transition to reusable packaging.

Fostplus

What is Fostplus's current vision regarding reusable packaging, specifically?

Lieven Capon: Many people forget that reusable packaging is not something new. In Belgium, 40% of the household packaging is already reusable. This mainly includes beverage packaging such as glass beer bottles, soft drinks, and water bottles – a segment that has been around for a long time and set up by the industry. However, in other sectors, we observe that reusable packaging is not gaining enough traction at the moment. This is partly due to some issues in making the entire logistics process work well and efficiently. In the coming years, we are fully committed to exploring the types of packaging, sectors, and products where reusable packaging can be a viable alternative.

Do you have any tips for food companies, packaging manufacturers, or laundry businesses regarding the use of reusable packaging?

Many companies are currently facing challenges with scalability & viability. This is something we won't be able to solve in the next few months or years. However, if I can offer a tip: approach it with an open mind. Not only because it's necessary, but it can also add value to the companies. Food companies want to sell as much of their product as possible, but they don't make money from packaging; it's an expense. As a food company, you can think in an open and constructive way about which products are suitable for reusable packaging and where there are opportunities and challenges. Try to embrace it as much as possible. It may not happen on a large scale in the next few years, but there is a lot in development. See it as an opportunity, not a threat. In addition to reusable packaging, there are also refillable packaging options. With this approach, consumers can bring their own container to a store to fill it. Here, the logistical element is placed in the hands of the consumer. These are other systems that you can keep in mind.

9. Next steps

› Interested or ideas for follow-up project?

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Contact Imec:
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› Own innovative ideas for a company specific project?

Website Flanders' FOOD:
ik wil een idee uitwerken

Contact Pack4Food:
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Flanders' FOOD is a cluster for the agri-food industry, supported by the Agency for Innovation and Entrepreneurship (VLAIO). The cluster aims to facilitate the collaboration between enterprises, knowledge institutes and governments. Discover all clusters at www.vlaio.be/clusters. **#growingstrong**

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This best practice guide has been developed for food companies, washing service providers, and integrators interested in using reusable packaging and smart camera systems for food applications.The guide provides insights from the VISION2REUSE project through practical examples, highlighting the use of smart cameras for automatic quality control of reusable packaging.Additionally, it offers design4reuse guidelines to facilitate easier cleaning of reusable packaging.

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