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Guest-Editor
Prof. Dr. Maria Athina Artavani, Hellenic Military Academy, Greece

Table of Contents

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Table of Contents

Approximating the "star points" for the 2d order Response Surface

Abstract:

The Response Surface Methodologies (RSM) play a very important role to the Experimental Design theory. The main feature are the so called star points (a) and their value is crucial depending on the number of the involved variables k. This paper offers an easy approximation of these values and a Geometrical justification for the proposed choice.

Keywords: Central Composite Designs (CCD), rotatability, star points

MSC Classification: 62K05, 62K20

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1. Introduction

We are interested in the problem of estimating a surface $q = q(x, y)$ by a set of n observations $y_i, i = 1, 2, \dots, n$ following the form $y_i = q(x, y) + e_i, i = 1, 2, \dots, n$ with e_i being independent random variables (identically distributed) known as errors. Thus estimating q by $q^* = q^*(x, y)$ we request, under some norm $||\cdot||_p$ to be

$$\min ||y_i - q||_p = ||y_i - q^*||_p \qquad (1)$$

With $p = 2$ we refer to the Euclidean norm introduced by (Legendre, 1806) and the underground procedure is usually the Least Squares method, introduced by Gauss, see (Stigler, 1981), (Herr, 1981).
With $p = 1$ the so called *taxicab* norm, or with $p = \infty$, the maximum norm, are usually more challenging in terms of calculations and therefore the $p = 2$ norm is usually applied.
In applications there are three main cases where a surface needs to be approximated:

(I) For a large area, a region, or a whole city, then Kriging method is the appropriate one, see (Iliopoulou & Kitsos, 2019) among others.

(II) When we refer to a "large response area" for an experiment in an airplane or a boat, we use the *B*-splines, (Entezari, Ville, & Möller, 2008).

(III) When we refer to an "experimental area" then the Response Surface Methods (RSM) are the appropriate tool to approximate the surface, see (Khuri & Cornell, 1996), (Myers & Montgomery, Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 1995), (Kitsos, Oliveira, & Oliveira, Geometrical and Optimization Aspects for Approximations the Response Surface in Industry, 2022).

The goal of this paper is to provide a concise presentation of the response surface design (RSD). The measure of the rotatable design, as well as the geometrical background, is also discussed and investigated trying to justify the value of the relevant "star" points. The Response Surface System (RSS) needs a certain measure of assurance and rotatability serves this purpose: to ensure that the predicted response is accurate. When orthogonal rotatable designs are requested more restrictions are needed: in principle when you offer more assumptions you gain more results. In order to determine a design's rotatability, new experiments are needed, so that the existing design can be formed to a rotatable one.

2. Geometrical Background

Now, consider the unit circle with equation $x^2 + y^2 = 1$ the ellipses (2) and (3) with foci in the x-axis

$$E_2: \frac{x^2}{2} + y^2 = 1 \qquad (2)$$

$$E_3: \frac{x^2}{3} + y^2 = 1 \qquad (3)$$

and the ellipses (4) and (5) with foci in the y-axis, see Figure 1.

$$E_2': \ x^2 + \frac{y^2}{2} = 1 \qquad (4)$$

$$E_3': \ x^2 + \frac{y^2}{3} = 1 \qquad (5)$$

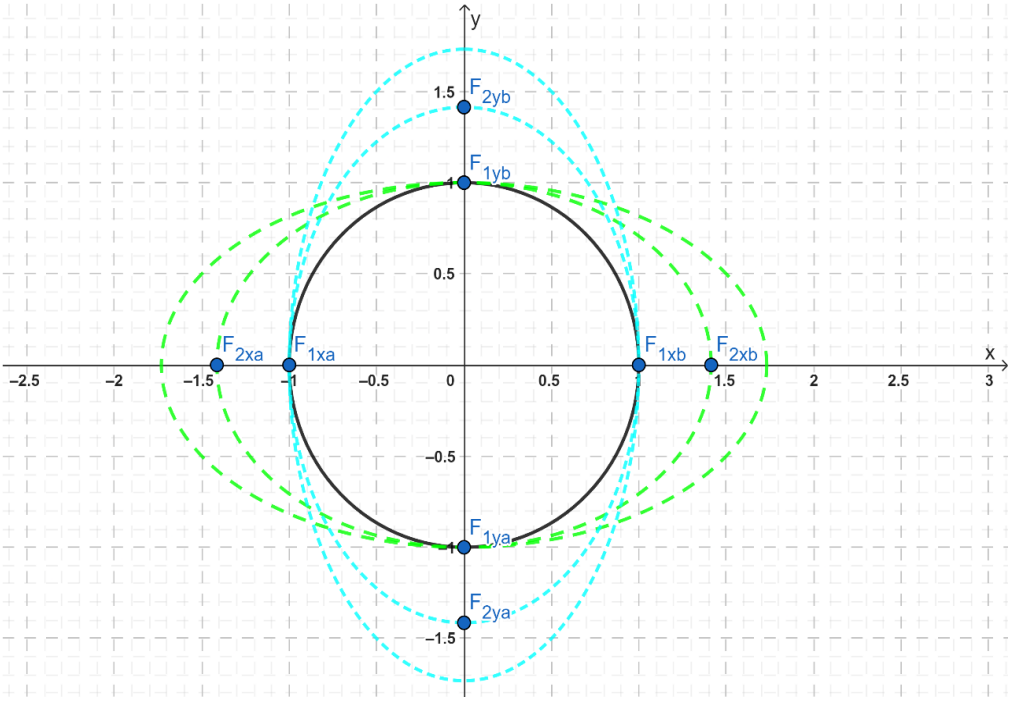

Figure 1: The unit circle and the ellipses with foci in the horizontal axis $(\pm\mathbf{1},\mathbf{0}),(\pm\sqrt{\mathbf{2}},\mathbf{0})$ and the vertical axis $(\mathbf{0},\pm\mathbf{1}),(\mathbf{0},\pm\sqrt{\mathbf{2}}\,)$.

Figure 1 will play an important role to our scenario to approximate the star values for the experiments investigating the response surface and verify the results with the simulations we perform.

The most well known second order Response Surface Designs are the Central Composite Designs (CCD), introduced by (Box & Wilson, On the experimental attainment of optimum conditions, 1951). More designs have been developed, the most important of which are: the Box-Behnken Design (BBD) introduced by (Box & Behnken, Some new three level designs for the study of quantitative variables, 1960), the Hybrid Designs (HD), introduced by (Roquemore, 1976), the Equiradial Designs (ED), introduced by (Draper & Hunter, 1966) and the Uniform Shell Designs introduced by (Doehlert, 1970).

We can always transform the experimental region Ω to a "squared" or "cylindrical" form, in the sense that

$$\Omega = [-1,1]^k \subseteq R^k \quad \text{or} \quad \Omega = \left\{x: \sum_{i=1}^{k} x_i^2 \leq 1\right\} \subseteq R^k \qquad (6)$$

For the RSD we usually require the condition

$$\text{var}\left(\hat{y}(x)\right) = \text{const, for all } x \in \Omega \text{ s.t. } ||x|| < r. \qquad (7)$$

We call the RSD rotatable, when the standardized variance function of the predicted response, is only a function of $\delta^2 = ||x||_2^2$, see also (7). We refer to (Kitsos, On the rotatability measure of the response surface designs, 1999) and (Khuri & Cornell, 1996) on the imposed conditions for a rotatable design and the technical benefits for such designs.

The input variables $x_1, \dots, x_k$ are related to the response $\mathbf{y} \in R^n$ with a physical way (usually through chemical experiments) as implied by the internal mechanistic model. In other words there exists a "smooth" function f such that

$$\mathrm{E}\,(y) := \eta = f(x_1, x_2, \dots, x_k) \tag{8}$$

Consider the following second order general linear model for the Response Surface

$$y = y(x) = \beta_0 + x^T\beta + x^T B\, x + e \tag{9}$$

where the transpose of x is $x^{\mathrm{T}} \in R^{1\times k}$, the square matrix $B = (\beta_{\mathrm{ij}}) \in R^{k\times k}$ has all of its elements, except the diagonal ones, divided by 2,

$$B = \begin{bmatrix} \beta_{11} & \frac{\beta_{12}}{2} & \cdots & \frac{\beta_{1k}}{2} \\ \frac{\beta_{21}}{2} & \beta_{22} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ \frac{\beta_{k1}}{2} & \frac{\beta_{k2}}{2} & \cdots & \beta_{kk} \end{bmatrix}$$

and for the independent identically distributed (i.i.d.) errors we assume that $e \sim N(0, \sigma^2 I_k)$ with $N(\mu, v)$ being the Normal distribution with mean μ and variance v. The input variables x_i are standardized as:

$$x_i = \frac{x_i - \bar{x}}{s_i}, \qquad \mathrm{s_i} = \frac{1}{n}\sum_{m=1}^{n}(x_m - \bar{x}_i), \qquad \bar{x}_i = \frac{1}{n}\sum_{m=1}^{n} x_m, \qquad i = 1, \dots, k \tag{10}$$

We refer to Chapter 6 in (Logothetis & Wynn, 1989) for the role of data transformation. The response surface is estimated by the second order surface

$$\hat{y}(x) = \hat{\beta}_0 + x^T\hat{\beta} + x^T\hat{B}\, x \tag{11}$$

and therefore the stationary point is

$$\mathrm{x_0} = -\frac{1}{2}\hat{B}^{-1}\hat{\beta} \tag{12}$$

see for details (Box & Draper, Some minimum point designs for second order response surfaces, 1974), (Kitsos, Oliveira, & Oliveira, Geometrical and Optimization Aspects for Approximations the Response Surface in Industry, 2022), (Khuri & Cornell, 1996), (Myers & Montgomery, Response Surface Methodology: Process

and Product Optimization Using Designed Experiments, 1995), while for a Linear Algebra approach to second order curves see (Amir-Moez & Fass, 1962).

3. Central Composite Design (CCD)

We are concentrated on the most useful in practice experimental designs: the Central Composite Designs (CCD). Let $N = N_F + N_S + N_C$ denote the total number of points that a CCD needs, where $N_F = r_F 2^{k-q}$ are the points from the 2^k factorial experiment replicated r_F times, $N_S = r_S 2k$ are the $2k$ star points replicated r_S times of the form $(\pm a, 0, \dots, 0), (0, \pm a, \dots, 0), \dots, (0, 0, \dots, \pm a)$ and N_C are the center points. Recall that the factorial experiment is the basis for this development, thanks to the pioneering work of (Yates, 1937). Therefore,

$$N = r_F 2^{k-q} + r_S 2k + N_C \tag{13}$$

The choice of the mean distance (a) of a particular star point on one axis of the coordinate system from the center $(0, 0, \dots, 0)$ makes the CCD:

i. Orthogonal (OCCD) when (a) is such that

$$a^2 = \frac{1}{2}\sqrt{N_F}\,(\sqrt{N} - \sqrt{N_F}) \tag{14}$$

ii. Rotatable (RCCD) when (a) is such that

$$a^2 = \sqrt{N_F} \quad \text{or equivalently} \quad a^4 = N_F \tag{15}$$

iii. OCCD and RCCD when (a) is such that (14) and (15) hold. It was pointed out (see p.550 in (Montgomery, 1991)and p.333 in (Myers & Montgomery, Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 1995) that

$$\alpha^2 = \frac{N_F(2k + N_{CA})}{2(N_F + N_{CF})} \tag{16}$$

where (see rel. (8.11) in (Khuri & Cornell, 1996) eventually the following equation holds

$$2N_F - \sqrt{N_F}(2k + N_{CA}) + 2N_{CF} = 0 \tag{17}$$

The following result is stated and proved in Kitsos (2019), clarifying the existence problem.

Theorem 1 (Kitsos (2019)) *The necessary and sufficient conditions for equation (17) to have positive and integer solutions are:*

i. $2 \mid N_{CA}$, i.e. N_{CA} is even

ii. $D = (2k + N_{CA})^2 - 16N_{CF} = \mu^2,\ \mu \in Z$, i.e. the discriminant of the quadratic equation (17) is positive with root an integer.

Corollary 2 *The required samples so that Theorem 1 holds are*

i. $N_{CF} = 2^{\frac{k}{2}-1}$

ii. $N_{CA} = p + 2^{\frac{k}{2}+1} - 2k,\ p \in Z^+$

The number of the appropriate values for N_F, N_{CA} and N_{CF} are discussed in Kitsos (2019).

Recall that the radius of curvature for the unit circle is $R_C = 1$ while for the ellipse, with the implicit equation

$$F(x,y) := \frac{x^2}{a^2} + \frac{y^2}{b^2} - 1 = 0 \qquad (18)$$

we find that its curvature is

$$\kappa_E(x,y) = \frac{\left|F_x^2 F_{yy} - 2F_x F_y F_{xy} + F_y^2 F_{xx}\right|}{\left(F_x^2 + F_y^2\right)^{\frac{3}{2}}} = \frac{\left(\frac{2}{a^2}x\right)^2 \frac{2}{b^2} + \left(\frac{2}{b^2}y\right)^2 \frac{2}{a^2}}{\left(\left(\frac{2}{a^2}x\right)^2 + \left(\frac{2}{b^2}y\right)^2\right)^{\frac{3}{2}}}$$

$$= \frac{a^4 b^4}{\left(b^4 x^2 + a^4 y^2\right)^{\frac{3}{2}}}$$

where F_x, F_y are the partial derivatives of F w.r.t x and y accordingly. Therefore the radius of curvature is the reciprocal of the above expression, see also Figure 2, for a given ellipse as in (18), that is

$$R_E = \frac{\left(b^4 x^2 + a^4 y^2\right)^{\frac{3}{2}}}{a^4 b^4} \qquad (19)$$

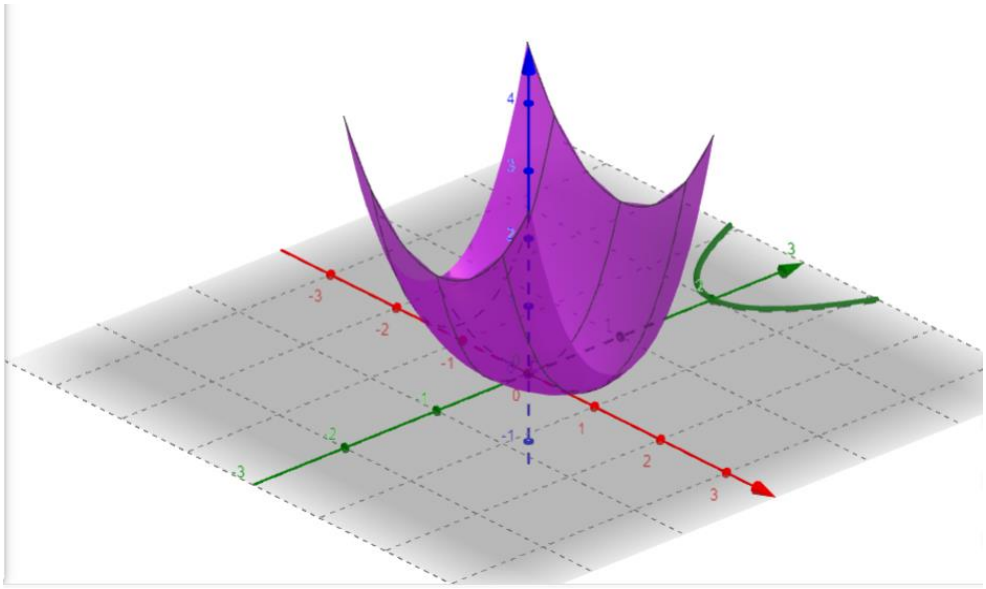

Figure 2: The radius of curvature $\boldsymbol{R_E}$ defined by (19) for $\boldsymbol{a = \sqrt{2}}$ and $\boldsymbol{b = 1}$.

The underlying Geometry to each problem plays an important role to face the proposed solution, see (Kitsos & Fatouros, Geometry in Quantitative Methods and Applications, 2023). Equation (18) represents an ellipse in an (x, y) plane: $\mathrm{E} := \{(\mathrm{x},\mathrm{y}) \in \mathrm{R}^2 \colon \mathrm{F}(\mathrm{x},\mathrm{y}) = 0\}$, see (2)-(5). Now, consider a transformation τ determined by the matrix

$$T = \begin{bmatrix} 1/a & 0 \\ 0 & 1/b \end{bmatrix}.$$

Then $T \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} X \\ Y \end{bmatrix}$. Note that $\mathrm{X}^2 + \mathrm{Y}^2 = 1$ so we get a unit circle in the (X, Y) plane

$$C := \{(X, Y) \in R^2 \colon X^2 + Y^2 = 1\}.$$

If we have a unit circle in the (X, Y) plane then the transformation with matrix

$$T^{-1} = \mathrm{diag}(a, b)$$

maps the points of the circle to an ellipse since by

$$T^{-1} \begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}$$

we find (18). Therefore it holds

Proposition 3 *There is a linear transformation* $\tau \colon E \mapsto C \colon x \mapsto Tx^T$. *As* $detT \neq 0$ *the inverse transformation* T^{-1} *always exists.*

Example 1 For the ellipse (2) which we rewrite as

$$E_2 \colon \frac{x^2}{\left(\sqrt{2}\right)^2} + \mathrm{y}^2 = 1$$

then $T_2 = \begin{bmatrix} \sqrt{2} & 0 \\ 0 & 1 \end{bmatrix}$. In principle for the E_{k} ellipse of the form

$$E_k: \ \frac{x^2}{(\sqrt{k})^2} + y^2 = 1 \qquad (20)$$

then $T_k = \begin{bmatrix} \sqrt{k} & 0 \\ 0 & 1 \end{bmatrix}$.

In a similar way for the ellipse (4)

$E_2': \ x^2 + \frac{y^2}{(\sqrt{2})^2} = 1$

the transformation matrix T_2' is the inverse of T_2 multiplied by $\det T_2$ that is

$$T_2' = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{2} \end{bmatrix}$$

and generally for the ellipse

$$E_k': \ x^2 + \frac{y^2}{(\sqrt{k})^2} = 1 \qquad (21)$$

then $T_k' = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{k} \end{bmatrix}$.

Notice that $T_k T_k' = \mathrm{diag}(\sqrt{k}, \sqrt{k})$. Furthermore, it is known that

Proposition 4 *The set* $G = \left\{ \begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix} : a > 0, b > 0 \right\}$ *is a group under multiplication.*

But let $G_1 = \left\{ \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{k} \end{bmatrix} : k \in N \right\}$ and $G_1 = \left\{ \begin{bmatrix} \sqrt{k} & 0 \\ 0 & 1 \end{bmatrix} : k \in N \right\}$.Then neither G_1 nor G_2 form a group.

The following discussion is related to the areas corresponding to ellipses E_k, say $|E_k|$. In particular for their area it holds that $|E_k| = |E_k'| = \pi\sqrt{k}$.

Moreover it is easy to see that

Proposition 5 *Let* E_k *be the ellipses (20) and* $|E_k|$ *the corresponding area, with the convention for* $k = 1, E_1 = C$ *with* $|E_1| = \pi$. *Then* $\{|E_k|\}_{k \in N}$ *is an increasing sequence with* $\frac{|E_{k+1}|}{|E_k|} = \sqrt{1 + \frac{1}{k}}$.

For the value of $|E_k|$, with k large, the transformation can be considered equiareal, $\frac{|E_{k+1}|}{|E_k|}$ tends to unity. But in RSM the value of k is usually up to 4 $(k = 2, 3, 4)$ and some times up to 6 $(k = 2, 3, 4, 5, 6)$, rarely can be 7. Therefore only approximations can be considered for equiareal.

4. Proposed Approximation

Recall that the necessary number of points of the design are related to the positive integer k see (13). Let $k = 1, 2, \dots, k_0$. Moreover the value of (a) for OCCD, RCCD and ORCCD is given by (14), (15) and (16) respectively. For $k = 2$ and $k = 4$ the values of (a) are exactly $\sqrt{k}$ while for $k = 3$ the approximation value works well and for $k = 6$ is in between. Since the case $k = 7$ is not a "good" approximation we set $k_0 = 6$. Therefore we will work with the unit circle $E_1 = C$ and $E_2, E_3, \dots, E_6$. Hence, the experimental region is the class $\cup_{j=1}^{k} E_j$ when the factors are $k = 1, \dots, 6$.

Notice that,

$$|E_{k+1}| - |E_k| = \left(\sqrt{k+1} - \sqrt{k}\right)\pi, \qquad k = 2, 3, \dots, k_0$$

while the area of the circle is $|E_1| = \pi$ thus

$$\frac{|E_k|}{|E_1|} = \sqrt{k}$$

That is, every new ellipse, moving from the experimental area defined by the unit circle is generated by "stretching" the end points $(-1,0), (1,0)$ on x-axis and $(0,-1), (0,1)$ on y-axis, adding a "little more" area, of order $\sqrt{k}$, while from ellipse E_k to E_{k+1} the experimental area is increased by $\left(\sqrt{k+1} - \sqrt{k}\right)\pi$. So moving "far" from the experimental region, recall the point (III) in Introduction, but still in the neighborhood of it, we try to investigate the $\min,$ or $\max$ of the Response Surface. The ellipse E_1 is the circle and the two foci coincide but moving from E_{k+1} to E_k ellipse the foci c, which in principle is $c = \sqrt{a^2 - b^2}$ (see (18)), now is $c_{k+1} = \sqrt{k+1-1} = a_k$ where $2a_k$ is the width of E_k.

Therefore for the sequence of ellipses $E_k, k = 1, 2, \dots$, but for the RSM $k = 1, 2, \dots, k_0$ the foci $(c_{k+1}, 0)$ is defined as

$$c_{k+1} = \sqrt{k} = a_k \text{ with } 2a_k \text{ is the width of } E_k$$

while $\frac{|E_{k+1}|}{|E_k|} = \sqrt{1+\frac{1}{k}}, k = 1,2,\dots,k_0$. The corresponding values for the star points (a) are referred to Table 4.3 in (Khuri & Cornell, 1996) and Table 7.6 in (Myers & Montgomery, Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 1995). The approximation we suggest is the value $(a) = \sqrt{k}$, which for $k = 2,4$ is the same for all the designs in Table 1 below. The above discussion can be formed as follows:

Proposition 6 For a CCD based on a 2^k factorial experiment the value of the star points in
$(a) \approx \sqrt{k}, \quad k = 2,3,4,5,6$

Therefore for the values of (a) related to the star points, the following Table 1 suggested

Table 1: Number of factors (k) and values of (a) for OCCD and RCCD

k	2	3	4	5	6
OCCD	1.4142	1.6330	2.0	2.3664	2.8284
RCCD	1.4142	1.6818	2.0	2.3784	2.3784
$\sqrt{k}$	1.4142	1.7320	2.0	2.2360	2.4494

We are working for this approximation with two examples from the literature to see how it works.

5. Examples

For a number of applications on RSM see (Leal, Oliveira, & Oliveira, 2014), (Oliveira, Leal, & Oliveira, 2015), while considering experimental designs for quality improvement see (Logothetis & Wynn, 1989). We used two already worked examples. We recalculated with R their results and then we followed the suggested approximation. The results we found are compared with the existed ones. No significance difference can be reported.

Example 2 We borrow an example from Section 5.6 in (Khuri & Cornell, 1996) where a CCD is applied for the estimation of snap bean yield surface which is affected by three ingredients: Nitrogen (N), Phosphoric Acid (P_2O_5) and Potash (K_2O). The levels of the three factors are coded in the following way

$$x_1 = \frac{N - 3.62}{1.59}, \qquad x_2 = \frac{P_2O_5 - 1.78}{0.71}, \qquad x_3 = \frac{K_2O - 2.42}{1.07}$$

N takes values from 0.866 to 6.373, P_2O_5 varies from 0.55 to 3.009 and K_2O from 0.566 to 4.273 all measured in pounds per plot and the average yield of snap beans. The experimental design uses five levels of each variable and six center point replications.

We want to fit a second-order model to the yield values of the form, see relation (9)

$$y = \beta_0 + \sum_{i=1}^{3} \beta_{ii} x_i + \sum_{i=1}^{3} \beta_{ii} x_i^2 + \sum_{i=1}^{3} \sum_{j=1}^{3} \beta_{ij} x_i x_j + e.$$

The fitted second-order model, where $\hat{\beta}$ is shown with four decimals, see Figure 9 for details of the response surface analysis performed using R, reads

$$\hat{y}(x) = 10.49 - 0.5611x_1 + 0.1753x_2 + 0.4531x_3 - 0.6552x_1^2 + 0.5132x_2^2 - 0.2752x_3^2 - 0.6775x_1x_2 + 1.1825x_1x_3 + 0.2325x_2x_3 \quad (22)$$

The coordinates of the stationary point are found to be

$$x_0 = \begin{bmatrix} -0.391 \\ -0.388 \\ -0.181 \end{bmatrix}$$

The estimated yield at x_0 is

$$\hat{y}(x_0) = \hat{\beta}_0 + \frac{1}{2} x_0^T \hat{\beta} = 10.49 + \frac{1}{2} [-0.391 \quad -0.388 \quad -0.181] \begin{bmatrix} -0.5611 \\ 0.1753 \\ 0.4531 \end{bmatrix}$$

$$= 10.5247 \quad (23)$$

while the evaluated yield in Section 5.6 in (Khuri & Cornell, 1996) is 10.5023.
The estimated eigenvalues of B that is of $\hat{B}$, see (9), where

$$B = \begin{bmatrix} \beta_{11} & \frac{\beta_{12}}{2} & \frac{\beta_{13}}{2} \\ \frac{\beta_{12}}{2} & \beta_{22} & \frac{\beta_{23}}{2} \\ \frac{\beta_{13}}{2} & \frac{\beta_{22}}{2} & \beta_{33} \end{bmatrix}$$

are

$$\lambda_1 = 0.6071, \quad \lambda_2 = 0.1325 \quad \text{and} \quad \lambda_3 = -1.1567$$

so the canonical equation of the snap bean yield surface is

$$\hat{y}_{CF} = 10.49 + 0.6071\, w_1^2 + 0.1325\, w_2^2 - 1.1567\, w_3^2 \quad (24)$$

In Table 2 we collect the values of the coefficients $\hat{\beta}$, the eigenvalues and the stationary point between the two designs. Recall that when $\lambda_i > 0, i = 1, 2, \ldots, k$, there is a minimum, while for $\lambda_i > 0, i = 1, 2, \ldots, k$ there is a maximum and when some are positive and some negative there is a saddle point, as it is the case here, which is also clear with Figures 5 and 6, cf. Myers and Montgomery (1995), Kitsos et. al. (2022).

Table 2: Estimation of $\hat{\beta}'$s and eigenvalues λ_i for the two designs in Example 2.

Coefficients	Model (22)	Model in Section 5.6 in (Khuri & Cornell, 1996)
$\hat{\beta}_0$	10.49	10.4624
$\hat{\beta}_1$	-0.5611	-0.57372
$\hat{\beta}_2$	0.17524	0.18336
$\hat{\beta}_3$	0.45311	0.45547
$\hat{\beta}_{11}$	-0.65516	-0.67636
$\hat{\beta}_{22}$	0.51317	0.56254
$\hat{\beta}_{33}$	-0.27516	-0.2734
$\hat{\beta}_{12}$	-0.6775	-0.6775
$\hat{\beta}_{13}$	1.1825	1.1825
$\hat{\beta}_{23}$	0.2325	0.2325
λ_1	0.6070612	0.650824
λ_2	0.1324745	0.1298285
λ_3	-1.1566785	1.1678697
x_0	$\begin{bmatrix} -0.3913059 \\ -0.3879556 \\ -0.1813681 \end{bmatrix}$	$\begin{bmatrix} -0.3942741 \\ -0.3643173 \\ -0.1745848 \end{bmatrix}$

In Figures 3 and 4 we worked out and we present a profile and a contour plot of the scaled variance for the two designs, using the *varfcn* function in R.

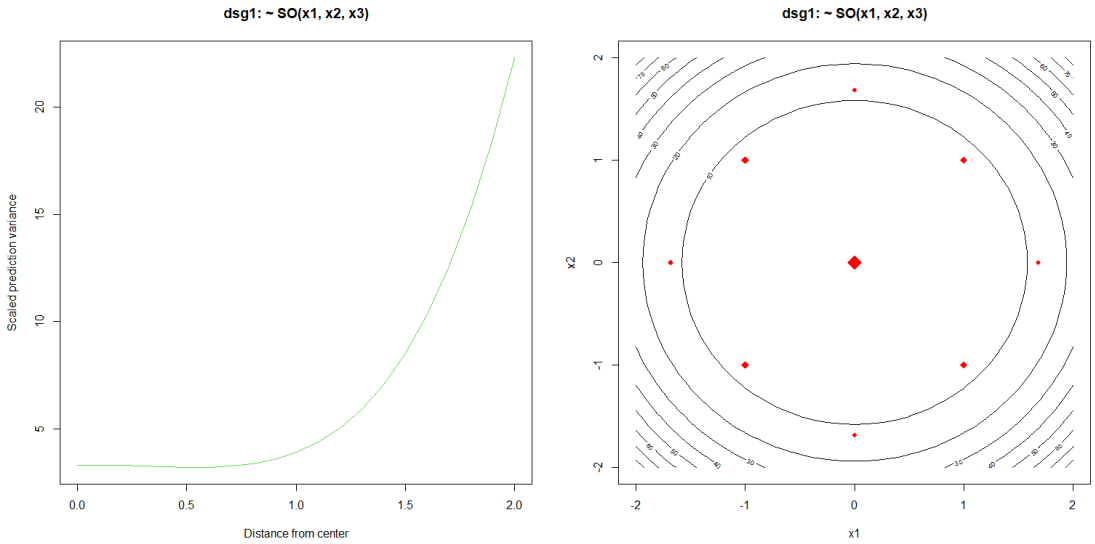

Figure 3: Plot of the scaled variance for the design in Section 5.6 in (Khuri & Cornell, 1996), Example 2.

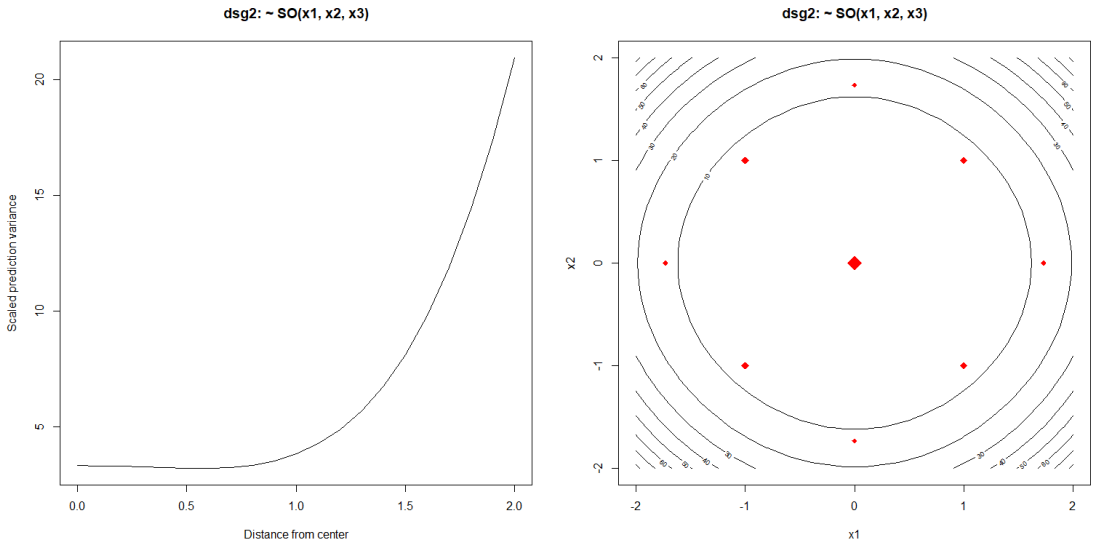

Figure 4: Plot of the scaled variance for the proposed design in Example 2.

Moreover, a slice of the fitted surface at the stationary point is found in Figures 5 and 6 accordingly.

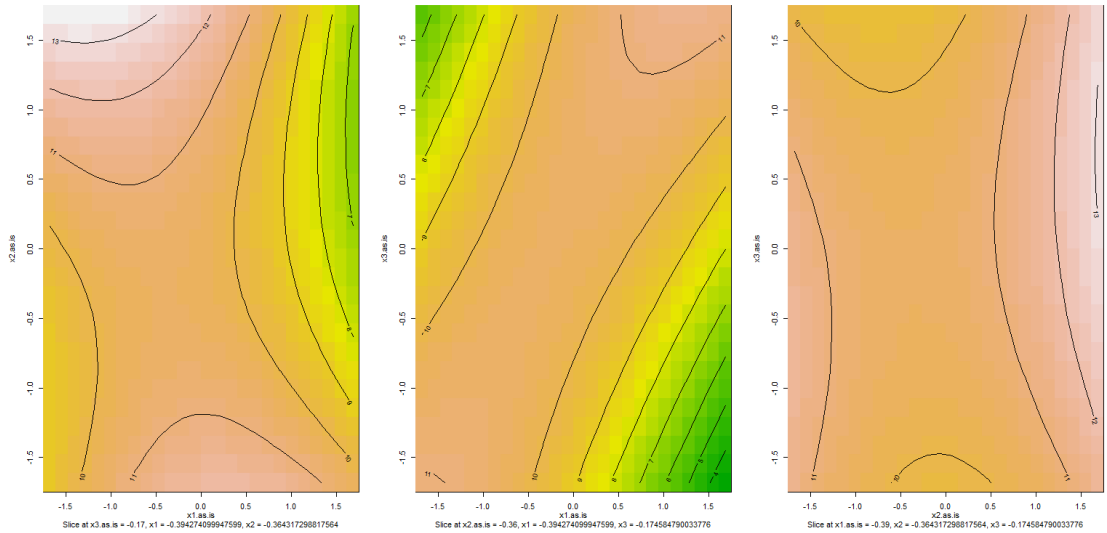

Figure 5: Slicing the fitted surface at the stationary point for the model in Section 5.6 in (Khuri & Cornell, 1996), Example 2.

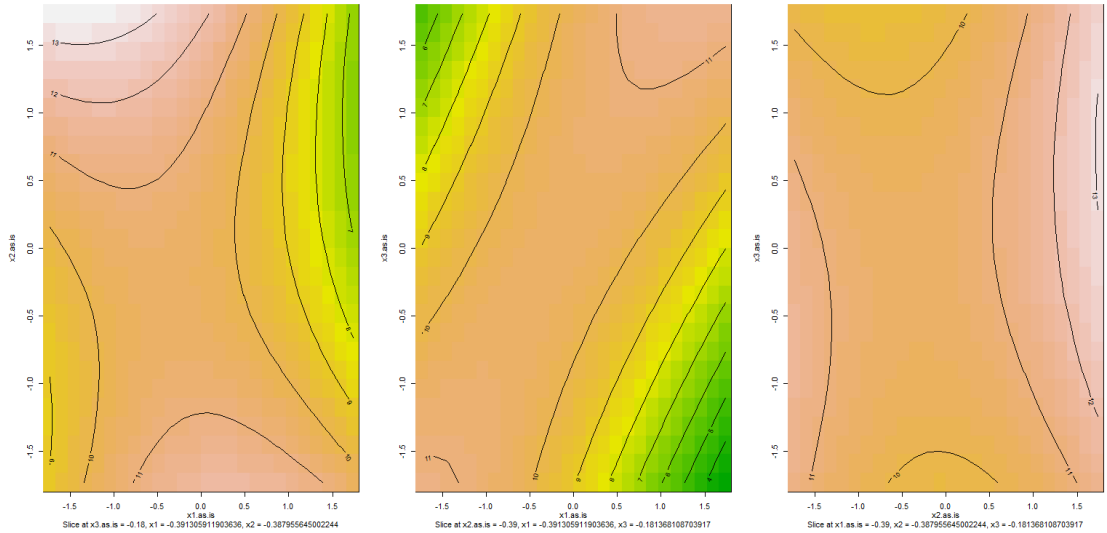

Figure 6: Slicing the fitted surface at the stationary point for the proposed model in Example 2.

It is clear from Figures 3, 4, 5, 6 that the approximation method provides the same graphical presentation.

Example 3 This experiment, taken from Myers and Montgomery (1995) Example 7.4 in studies the response surface relating the strength of breadwrapper stock (grams/inch^2), to sealing temperature (ST), cooling bar temperature (CT) (in F) and percent polyethylene (PE) additive. The design levels are

$$x_1 = \frac{ST - 255°F}{30}, \qquad x_2 = \frac{CT - 55°F}{9}, \qquad x_3 = \frac{PE - 1.1\%}{0.6}$$

Again there are five levels for each variable and six center point replications.
The fitted second-order model, see Figure 12, reads

$$\hat{y}(x) = 10.2 - 1.0938x_1 + 0.0829x_2 + 1.01196x_3 - 0.7651x_1^2 - 1.0317x_2^2 - 1.1317x_3^2 - 0.35x_1x_2 - 0.5x_1x_3 + 0.15x_2x_3 \quad (25)$$

The stationary point is located at $x_0 = [-0.998 \quad 0.259 \quad 0.685]^T$. The estimated strength at x_0 is

$$\hat{y}(x_0) = 10.2 + \frac{1}{2}[-0.998 \quad 0.259 \quad 0.685]\begin{bmatrix} -1.0938 \\ 0.0829 \\ 1.01196 \end{bmatrix} = 11.1031 \quad (26)$$

while the evaluated strength in is 11.08, Montgomery and Myers (1995). The estimated eigenvalues of $\widehat{B}$ are $\lambda_1 = -0.561$, $\lambda_2 = -1.1085$ and $\lambda_3 = -1.259$. all the eigenvalues are negative, so there is a maximum and the canonical form is given by , Table 3

$$\hat{y}_{CF} = 11.1031 - 0.561w_1^2 - 1.1085w_2^2 - 1.259\,w_3^2 \quad (27)$$

6. Discussion

It is true that in Statistics, as a rule, we try a number of simulations, usually 1000, and the MSE (Mean Square Error) is evaluated. We worked with distance measure to examine our results. The details are in this section. We need a method to compare how different are the evaluated models. Their presentation, see Figures 5 – 6 is identical. Comparing the evaluations in both examples we are adopting a distance measure to see "how far" are the estimated curves and the corresponding stationary points for both used models. A way to measure how "close" the produced fitted second-order models are, is by considering the Euclidean distance, L_2-norm, induced by the inner product for two, in principle smooth functions f, g:

$$||f - g|| = < f - g, f - g >^{1/2} = \sqrt{\int \left(f(\mathbf{x}) - g(\mathbf{x})\right)^2 d\mathbf{x}}$$

Table 3: Estimation of $\hat{\beta}'$s and eigenvalues λ_i for the two designs in Example 3.

Coefficients	Model (25)	Model in Example 7.4 in (Myers & Montgomery, Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 1995)
$\hat{\beta}_0$	10.2	10.1649
$\hat{\beta}_1$	-1.0938	-1.1036
$\hat{\beta}_2$	0.0829	0.087185
$\hat{\beta}_3$	1.01196	1.02042
$\hat{\beta}_{11}$	-0.7651	-0.7596
$\hat{\beta}_{22}$	-1.0317	-1.0424
$\hat{\beta}_{33}$	-1.1317	-1.1484

$\hat{\beta}_{12}$	-0.35	-0.35
$\hat{\beta}_{13}$	-0.5	-0.5
$\hat{\beta}_{23}$	0.15	0.15
λ_1	-0.5616	-0.5621
λ_2	-1.1077	-1.1172
λ_3	-1.2593	-1.2713
x_0	$\begin{bmatrix}-0.998\\0.259\\0.685\end{bmatrix}$	$\begin{bmatrix}-1.011\\0.261\\0.681\end{bmatrix}$

Therefore, if we denote by $\hat{y}_1(x)$ the proposed model and by $\hat{y}_2(x)$ the CCD model referred in the preceding examples then for Example 2 we have that

$$||\hat{y}_1 - \hat{y}_2|| = \sqrt{\int_{-\sqrt{3}}^{\sqrt{3}}\int_{-\sqrt{3}}^{\sqrt{3}}\int_{-\sqrt{3}}^{\sqrt{3}} \left(\hat{y}_1(x_1,x_2,x_3) - \hat{y}_2(x_1,x_2,x_3)\right)^2 dx_1 dx_2 dx_3} = \sqrt{0.105924}$$

$$= 0.3254$$

and for Example 3 we find that

$$||\hat{y}_1 - \hat{y}_2||_2 = \sqrt{0.156877} = 0.3961$$

therefore this norm is <1. Moreover, the way the stationary points differ can be calculated by

$$||x_0^1 - x_0^2||_2 = \sqrt{\sum_{i=1}^{3} |x_0^1(i) - x_0^2(i)|^2}$$

We compute this difference as 0.0248 for Example 2 and 0.0137 for Example 3, both less than 0.1, hence the stationary points are very close to be identical.

Finally, the differences of the estimated values at the stationary point are of the order 0.1 since for Example 2, see (23), we find

$$|\hat{y}_1(x_0) - \hat{y}_2(x_0)| = 0.0224$$

and for Example 3, see (26), we compute $|\hat{y}_1(x_0) - \hat{y}_2(x_0)| = 0.0231$. Therefore the evaluated approximated values offer an approximation of order 10^{-1} under the provided Geometrical explanation we developed.

In this paper we worked with the "distance method" to see how close the results with the proposed approximation with the existing ones are. We decided to present these mathematical simple calculations for the distance to emphasize its importance. The benefit of this quick method is clear as the experiments confirm. We can provide the calculations upon request.

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Introducing Geographical Information Systems (GIS) on Secondary Education to Enhance Student Learning

Abstract:

Geographical Information Systems (GIS) consists of a progressively imperative technology that has been recognized as multifaceted technology with a powerful visual dimension that carries great potential for enhancing and creating highly informed spatial decisions. Although it was not designed for educational purposes, educators have begun to use GIS in various disciplines over the last decade with numerus benefits within the teaching–learning context. This paper, describes an initiative to introduce GIS-related topics on secondary education and deliver effective development experiences using some basic notions and technologies in their classroom and learning environment. The overall conceptual framework based on short and interactive presentations with versatile use of geomedia along with a hands-on workshop. Some preliminary results showed that the use of such technologies positively affected the attitude of the students and their motivation, welcoming alternatives to traditional learning methods. From this standpoint, it is also evident that for the successful use of GIS in the classroom, must be supported from adequate technology and educational infrastructure with the guidance of a well-trained and knowledge Geography teachers.

Keywords: GIS, Geography Teaching, Secondary Education, Spatial Thinking

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1. Introduction

Geographic Information System (GIS) is a tool for examine the real word and manage data that has spatial information (Bakri et al., 2019; Bernhäuserová et al., 2022). It is a progressively imperative technology that has been globally recognized as a multifaceted technology with a powerful visual dimension that carries great potential for enhancing and creating highly informed spatial decisions (Bearman et al., 2016; Mkhongi & Musakwa, 2020). By definition, GIS is a set of integrated software programs designed to collect location information, store, retrieve, analyze, managing and presenting geographical data-information (Demirci, 2008, 2009; Mkhongi & Musakwa, 2020).

GIS has revolutionized the methods and dimensions of spatial analysis resulting in a dramatic change in the direction of Geography and became a major component in other disciplines with a spatial component (Demirci, 2008). For this reason, is completely within the scope of interdisciplinary studies, combining data from various and different fields (Demirci, 2008, 2009).

Although it was not designed for educational purposes and as GIS become simpler, more user-friendly, and, therefore, easier and more practical to use, educators have begun to use it in various disciplines over the last decade (Bernhäuserová et al., 2022; Lee, 2020). As an educational tool, it can enhance education in geography contributing diverse benefits within the teaching–learning context, specifically in helping students understand geographical concepts (Bernhäuserová et al., 2022) and analyze relationships among spatial phenomena (Mejía Ávila et al., 2021); increase the success of cooperative learning and collaboration in the classroom (Bakri et al., 2019); improved motivation, attitude, and ability to understand (Incekara, 2012; Mejía Ávila et al., 2021; Prof & Ateş, 2013); support application problem solving (Demirci et al., 2013; Mkhongi & Musakwa, 2020); solve discipline specific problems (Bernhäuserová et al., 2022); develop higher-order thinking skills and increase spatial thinking or awareness (Madsen & Rump, 2012; Withambednarz, 2004); and emphasize the synthetical nature of the discipline of geography (Bernhäuserová et al., 2022). GIS is therefore relevant given the current wave of the fourth industrial revolution (Mkhongi & Musakwa, 2020).

However, despite the extensive discussion on the justification of GIS use in lessons and the necessary changes made in the curriculum, the implementation of GIS in teaching is challenging and has been relatively slow (Anunti et al., 2020; Höhnle et al., 2015). It is evident that some variables limit the process of GIS implementation in lessons such as teacher's perception about the need of those systems, limited exposure of educators to GIS application skills and knowledge, as well as inadequate educator development and pedagogical guidance (Bernhäuserová et al., 2022; Mkhongi & Musakwa, 2020).

Developed countries such as the United States, the United Kingdom, Canada and Australia are amongst the few leaders of GIS education (Baker & White, 2003). Denmark, China, France, Sweden, Finland and Japan also form part of countries that are well-equipped to utilize GIS resources (Mkhongi & Musakwa, 2020) and use it in geography and together with sciences, chemistry, biology, math, environmental sciences and social sciences as well in their secondary education schools (Demirci, 2009). However, developing countries are lagging behind as they are in the early implementation stages of GIS education in high schools (Kholoshyn et al., 2021). In Cyprus, GIS education is not included on curriculum or even implemented on any school grade.

Objectives

The objectives of the initiative were to: (1) Develop and deliver effective development experiences on secondary school students using GIS theory and technologies in their classroom and learning environments; (2) Showcase GIS applications of everyday and real-life examples; (3) Encourage and promote education in GIS-related topics to raise awareness; (4) Introducing new technologies on learning process along with hands-on examples, and; (5) Support students during their first contact with research and technology.

The paper is organized as follows: A comprehensive review of the proposed learning methodology used is summarized in Section 2. A presentation of some preliminary results is given in Section 3, while Section 4, presents the concluding remarks and discusses future work aspects.

2. Methods

The overall conceptual framework of the present study, based on 2 phases to promote education and outreach in GIS-related topics in Cyprus secondary schools, enhancing the geography curriculum for secondary schools. The aim is to produce instructional materials through a carefully designed and properly executed process to address the needs and demands of the students in a digital and rapidly changing world in a non-such flexible education system.

In the first phase (Phase I), presentations were conducted to inform and introduce students about the concept of GIS, some basic notions along with their evolution during the time and the future perspective of these systems. The presentations conclude with several real-life examples of how these systems are used in emergency response situations, on traffic monitoring, on environmental protection, on education in other countries and as a decision support tool for the stakeholders. The research aspect of these systems is also presented, introducing the new era of GIS on interconnectivity with other systems, on real-time monitoring, data exchange and dynamic virtual of physical or technical assets by introducing digital twins and artificial intelligence. Instructional material built upon students' prior knowledge and skills and focus to introduce new aspects of geography to support their learning methods. Presentations were kept short (~40 min) and interactive, with versatile use of geomedia (static maps, web maps, diagrams, images, videos, and other media). After the presentation was conducted, open discussion was promoted with the students, asking about the effectiveness of the presentation and how useful it was for them, tracking their thoughts and ideas.

In the second phase (Phase II), workshops were organized for practical training in which students introduced and used open-source GIS software (QGIS) in their school's laboratory. Workshops were conducted on a different day than presentations, having a 2-hour duration (students are divided into four groups). A set of guidelines shared with students, containing practical instructions and assignments to produce thematic maps covering social and environmental aspects of their everyday life. The guidelines can be described as a cookbook with recipe-like text that must be followed closely by the students to do the assignments and obtain a successful outcome and does not encourage the students to explore the used software. Thus, it does not support the students in constructing their own perception of the spatial issues dealt with in the specific exercise. Rather it directs the student's attention towards GIS as an object, and hence it may not be very helpful for the students in the instrumentation process (Madsen & Rump, 2012). In addition, external support and direction to students has been provided from both the instructor and their teacher during the workshops. The importance of data availability and validity were also highlighted during this phase, focusing on the visual concept of maps and how they can represent the same information in different ways. Collecting data and digitizing were not part of the workshop. Instead, it was based on observations of data given or accessed from Cyprus open data portal (Open Data, 2023) by identifying different relationships and conducting basic spatial analysis operations. The main aim of these activities was to challenge students´ spatial thinking and use a variety of geographical practices and tools on their learning environment. Observations and comments collected to identify if the students retained the skills and knowledge obtained during the workshop.

, presents a high-level overview of the overall instructional method phases that used focusing on what is GIS, the timeline of these systems, a show case of some real-life applications in regional and global level and the implementation of the workshop.

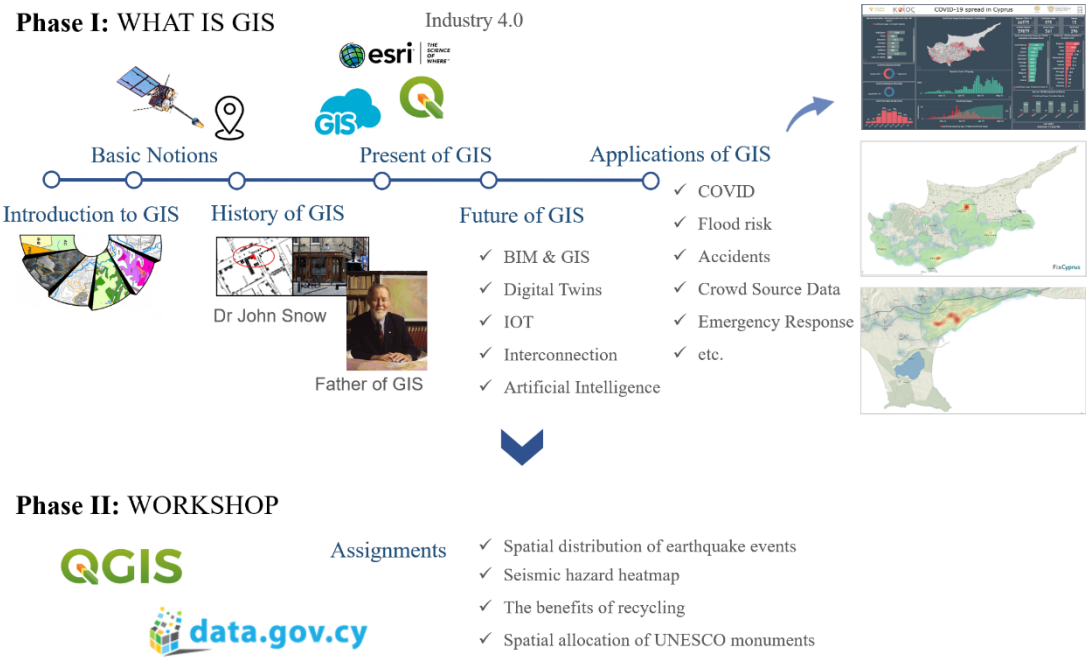

Figure 1: Instructional phases overview (FixCyprus, 2023; KIOS CoE, 2023; Open Data, 2023).

3. Discussion and Preliminary Results

The initiative was conducted at secondary schools in the greater area of Nicosia during the Geography lesson. The participating students (*n*=150) were aged between 12 and 14 years from first to third grade (Figure 2).

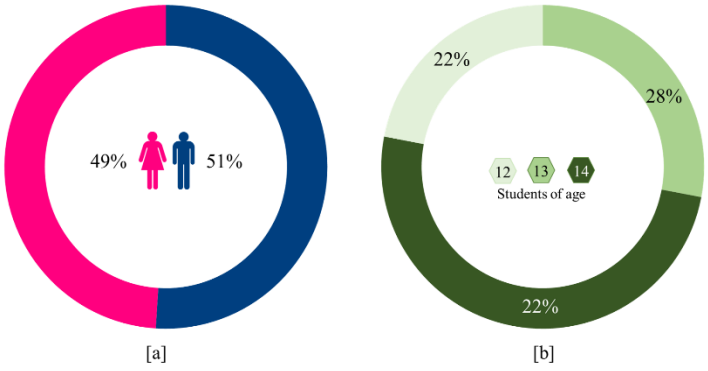

Figure 2: Demographic statistics of the participated students where: (a) refers to gender; (b) refers to age range of the students.

Phase I and introduction course, revealed the potential of GIS as a tool for improving the learning experience of the students through interactive methods, visualization techniques along with geomedia support. Students were able to enhance their understanding about what is GIS, the possibilities of it in different sectors of society such as science, education, work-life as well as in everyday life. Their positive attitude and high-level motivation are indicated by their responses, questions, and participation during the course. Students enjoyed participating in classrooms where GIS is used as these classes become more interesting and active. Results also showed that geographical thinking increased as students developed the ability to pose geographical questions and use of geomedia to solve theoretical geographical problems.

Implementing Phase II, met well the objectives that have been set. Even though the most challenging and time-consuming thing it was the learning of the software and how to use it, students improved their skills in to acquire, process, analyze, interpret, evaluate, and present geographic data during the completion of their assignments. The following figures present the results of the workshop assignments

that students had to accomplish using the provided step-by-step guideline set. Figure 3 (a-b) use the same dataset origin from Cyprus open data portal (Open Data, 2023) that refers to earthquake events during 2022 over the greater area of Cyprus. Figure 3 (a) present the spatial distribution of earthquake events classified per magnitude while Figure 3 (b) focuses on seismic hazard hotspots. In the other hand, Figure 4 (a) highlight the benefits of the recycle process, indicating the allocation of recycle positions for glass, PMD and paper materials (Green-dot, 2023). Finally, Figure 4 (b) aims to help students to identify the World Heritage Sites designated by UNESCO for having cultural, historical, scientific, or other forms of significance over Cyprus (UNESCO, 2023).

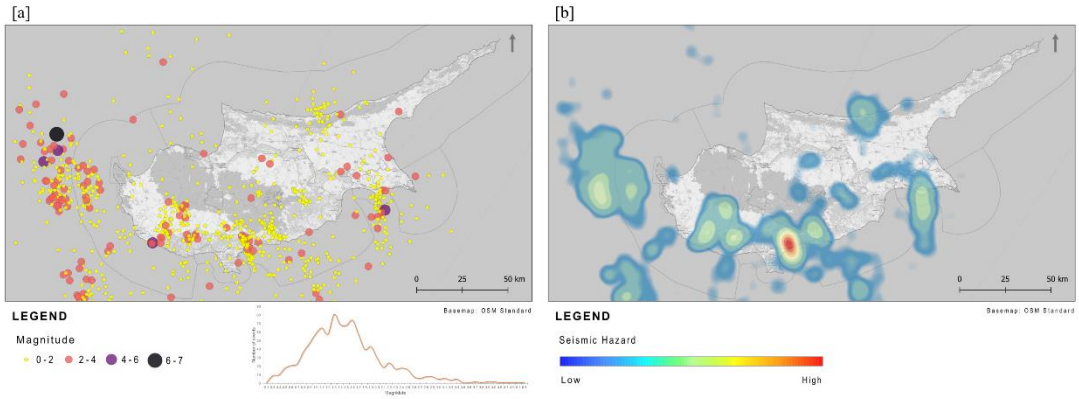

Figure 3: Workshop assignments where the maps refer to: (a) Spatial distribution of earthquake events; (b) Seismic hazard hotspots.

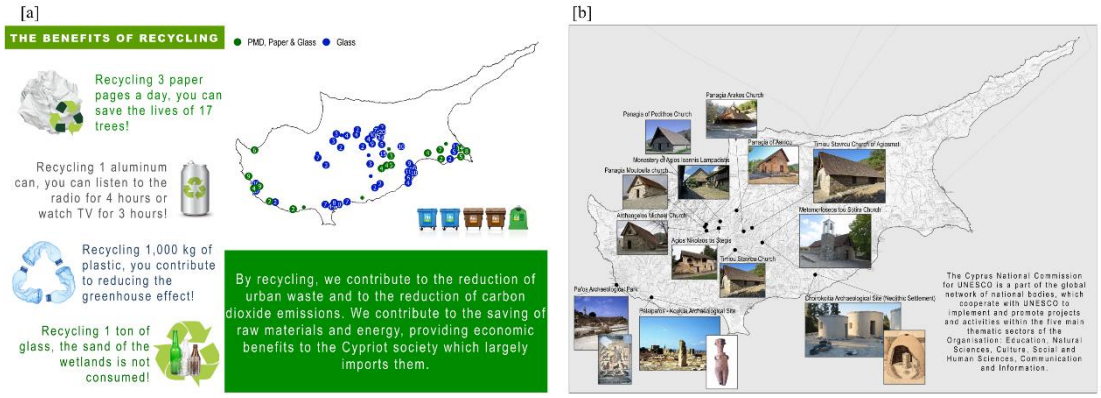

Figure 4: Workshop assignments where the maps refer to: (a) The benefits of recycling; (b) Spatial allocation of UNESCO monuments.

The findings of these assignments strongly indicate that a teacher is needed to guide the student-centered learning process throughout the workshop with assistance from the instructor as confirmed from previous studies as well (Anunti et al., 2020; Esteves & Rocha, 2015). To teach GIS skills effectively to students, the teacher needs to be competent and know those skills well. Moreover, even although there are not statistically representative results due to the lack of quantitative or qualitative feedback from students, the results from the open discussion provide a starting platform towards the need for more interactive lessons using technology-supported methods, tools, and media into the curriculum for secondary schools. It will help students to strengthen their interest, improve their performance and support them in acquiring necessary skills such as critical thinking, spatial thinking, creativity, collaboration etc.

Issues and problems

Due to the affection and constraint of many factors, the possibility of integration of GIS into secondary education, at least in near future, will phase many problems, as identified from this initiative. These factors include:

- Learning and implementation of GIS takes a long time and thus sufficient time in the curriculum to better incorporate GIS into education is needed through the lesson of Geography.
- The curriculum must be enriched with all necessary digital data, lesson plans and learning objectives.
- Some teachers have negative perceptions of technology and negative conceptions of geography that makes it difficult in incorporating GIS into their courses.
- There is a noticeable lack of necessary GIS skills and knowledge of Geography teachers.
- Lack of access to appropriate equipment (hardware and software), educational technologies and access to the Internet and Internet-based applications.
- Limited physical infrastructures and facilities of schools prevented the efficient use of technology in their courses.

4. Conclusions

The objectives of this work were the introduction of new technologies and GIS-related topics on learning process and environments on secondary education. Effective development experiences promoted through instructional material and a carefully designed and properly executed process. Teaching with GIS provides the opportunity for issues-based, student-centered, standards-based, inquiry-oriented education, but its effectiveness is limited primarily by social, structural and technological barriers along with luck of knowledge from teachers, as also stated from previous works (Bearman et al., 2016; Bernhäuserová et al., 2022; Kerski, 2003; Schulze, 2021).

Nevertheless, the major findings of this work can be summarized in some key points. First, GIS helped students to develop spatial thinking skills by exposing them to real-life examples and thematic mapping assignments. The geography lesson became more visual using geomedia, and positively affected the attitude of the students and their motivation. Another key point is that with the GIS-based applications and workshop assignments, students became more interested in new technologies and methods welcoming alternatives to traditional learning methods. From this standpoint, it is also evident that for the successful use of GIS in the classroom, there must be adequate technology and supporting educational infrastructure. Finally, the use of GIS tools along with the interactive learning approach, is another important component singled out by students, which may be an indication for more active role in the teaching process from students, and an expression of the need to modernization of teaching.

Feature work

Given the importance of introducing new technologies, methods, and knowledge to learning environments, the following aspects should be taken into consideration for improving students learning experience on GIS-related topics.

First, it must be identified a method to employ to measure progress towards meeting the initiative objectives. This method must be used in feedback loops to guide the successive development of the resulting experience (Anunti et al., 2020; McClurg & Buss, 2007). The use of surveys before and after each phase, the further collection of qualitative and quantitative data respectively, enables the acquisition of both an overview about the general nature of responses as well as gaining deeper insights into the topic (Anunti et al., 2020). Moreover, the intensive 2-hr long workshop format must be modified to a series of two-day sessions to provide students with opportunities to test and refine their skills at home and in the classroom between sessions. The first meeting shall introduce students to the basic functions of the software that will use, including adding data layers, conducting spatial queries, and creating layouts. A key feature is a field trip for data collection, including the use of their mobile devices and relevant GIS applications. That will provide great facilities to support the individual formation of knowledge based on data collection (Chatel & Falk, 2017; Lee, 2020). The second meeting will focus on the use of GIS for thematic mapping and how important is data visualization.

Finally, an additional measure that will improve integration and retention is the need for homework assignments between workshop sessions (McClurg & Buss, 2007). This will include the use of web-based tools such as Google Earth or Google Maps that have high educational potentials (Mejía Ávila et al., 2021) or a more advance tools such as ArcGIS Story Maps provided by ESRI as a tool which both

effectively communicates and visualizes complicated ideas and large amounts of information in an organized, user-friendly interface (Cope et al., 2018; Cyvin et al., 2022).

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Development of an Innovative Integrated Maritime Surveillance Platform Using Multiple Sensors and Information Sources

Abstract:
Nowadays, an ever-increasing number of maritime authorities, such as Coast Guards, Fisheries Control Agencies, Border Guards, Police Forces, Maritime Safety Authorities, Ports and Customs need to know the positions, activities and cargoes of vessels operating within their maritime jurisdiction. In this direction, many systems and databases have already been implemented, such as Vessel Traffic Monitoring System (VTMS), Vessel Monitoring Systems (VMS), Automatic Identification Systems (AIS), SafeSeaNet (SSN), etc. These systems are designed to meet EU requirements or international regulations adopted by the International Maritime Organization (IMO), but there is no provision for interoperability between them to ensure a single and complete picture of the maritime domain, which helps and makes surveillance more effective. This paper develops an integrated network of the existing maritime traffic control and surveillance systems for the area of interest (Greece), so that the overall picture of the maritime domain is gathered on a single platform. The multi-layered platform will allow the monitoring of various parameters, threats and events, including surveillance of national maritime space, migration flows, natural disasters, environmental issues, accidents, etc.

Keywords: Border Safe platform, Border surveillance system, Multi-layered platform, National maritime surveillance

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1. Introduction

Maritime surveillance is carried out by national authorities, mainly to detect and prevent regulatory violations and security threats. Surveillance is a key element in the exercise of national sovereignty at sea and is carried out for various reasons such as, fisheries control, environmental protection, maritime transport security, border control, illegal immigration control, etc. [1]. Today, maritime surveillance can be implemented using a variety of methodologies and tools, using either cooperative systems (in which ships themselves report their identities and positions), such as the Automatic Identification System (AIS), Long Range Identification and Tracking (LRIT) and Vessel Monitoring System (VMS), or non-cooperative systems, which do not demand any action from the side of the ships. The latter typically use cameras or radars installed on platforms (e.g. ships, airplanes, satellites) [2]. Although many systems have been implemented to date for maritime traffic surveillance (VTMS, SAFESEANET), fishing vessels surveillance (VMS), and collision avoidance (AIS) [3] [4], there is no provision for interoperability between them. At the national level there are many different systems that are a source of information for the Hellenic Coast Guard about activities at sea, but without any integration/interoperability among them [5]. Within this context, the paper presents a single multi-layered platform for monitoring various parameters, threats and events, gathering the overall picture of the maritime domain on a single platform.

The Border Safe Platform is based on the research effort of the Border-Guards system, which aims to find alternative affordable options, able to offer fast and low-cost reliable solutions, to meet the imperative needs of surveillance of the national maritime space. Thus, the guiding principle of the present research effort is focused on the reasoning that the multifaceted nature of the study area requires the use of an ever-growing and expanding network of multiple sensors and information sources. The sensors supporting the system can include any useful types (e.g. radar, AIS receivers, cameras, drones, etc.), should be low cost (purchase and operation) and easily replaceable (off-the-self). The system will be interconnected via the internet, without excluding other forms of interconnection, such as Wi-Fi, radio links, etc.

The system should also monitor developments in the field of Earth Observation (EO) and develop its ability to exploit information derived from satellite data. Finally, it uses any online sources of information capable of enriching the situation awareness picture (e.g. meteorological and oceanographic data, historical statistical data, etc.). The functions of the platform will be the real added value in research and technological development, in all stages of risk management-event detection, alarm warning, data fusion-continuous tracking (e.g. weather conditions, fires, environmental pollution on land and sea, refugee flows, shipwrecks, criminal activities, etc.), and notification of persons in charge, with applications to surveillance technologies.

In this paper, the following sections discuss the design of the platform and its main features and functions. More specifically, after an introduction to the study area and the existing maritime surveillance systems, the Border Safe platform is described in detail. Finally, future research steps and conclusions are summarized in the last sections.

2. Current Situation and Needs in Maritime Surveillance

The surveillance of the national maritime space, which is also the EU's external maritime border, close to the destabilized Middle East and North Africa, is undoubtedly a difficult and complex task. Especially today, as the region is under extremely high pressure, from the large wave of migration flows to the EU. The extensive coastline, about 18.400 kilometers, both continental and that of the numerous islands and islets (about 9.000) which are scattered in the seas surrounding the country, create the most favourable conditions for border violations. This is not only related to migrant smuggling, but also includes other smuggling activities, such as smuggling and trafficking of fuel, cigarettes, drugs and weapons. The maritime trafficking and border violations observed in the region are unfortunately complex, compared to other Mediterranean regions.

This is due to the fact that distances between the point of departure and destination vary, from very close (e.g. Eastern Aegean Islands-Turkey), where they allow the use of dinghies or other small vessels, to long where larger vessels of almost all types are involved. These conditions create the need for systematic surveillance of the extensive maritime border zones, far exceeding the capabilities of the

limited patrolling means of the Hellenic Coast Guard. The situation becomes even more complex, due to the intense international and local shipping activity that takes place in the area (Fig.1) [6]. The first concerns international maritime transport with ships of all types crossing the Greek seas. At least 50.000 ships pass through the Aegean Sea every year, as it is a corridor between the Mediterranean and the Black Sea [7]. The second concerns coastal shipping connecting the islands to the mainland and to each other, as well as intensive fishing and recreational activity including cruise ships, yachts and pleasure boats.

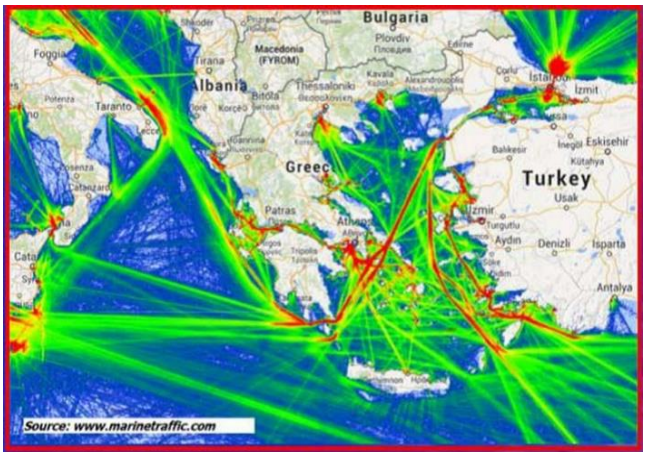

Figure 5. Shipping density based on AIS data Source: MarineTraffic 2023

Thus, the particularities of the area require, as a key element of an integrated surveillance system, the ability of distinguishing between non-cooperatives and cooperative vessels, i.e. those that comply with AIS signal transmission requirements and those that do not transmit or transmit with long interruptions. It is obvious that in order to achieve this goal, in addition to an extensive network of AIS receivers covering the area, which already exists to a large extent, the ability to detect ships moving in the area is also required, through independent sensors such as radars. This refers to an integrated system such as VTMIS (Vessel Traffic Monitoring and Identification System). In 1996, the development study of the national VTMIS system was completed, for the development of VTS (Vessel Traffic Service) centers in the wider Greek maritime area. Based on this study, an international tender was announced in 1998 for the implementation of the first phase of the national VTMIS [8], [9]. Although the first phase of the national VTMIS has been implemented, it only covers the Saronic Gulf, South Evia, a small part of the Central Aegean Sea, the Gulf of Patras and the sea zone between Corfu and Igoumenitsa (Fig.2).

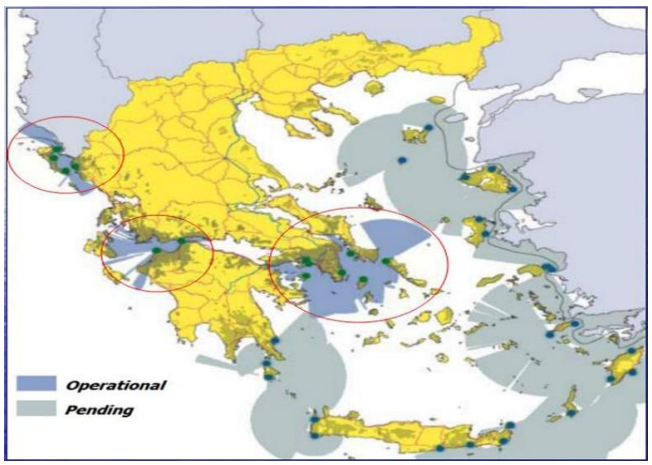

Figure 2. National VTMIS system. Source: PoliceNet, 2014

Unfortunately, the second phase, which is planned to cover areas of the Eastern Aegean Sea and the straits of Kythira and Karpathos has not yet been implemented. However, as shown in Figure 2 even when second phase is implemented, extensive areas of Greek seas will remain unmonitored, continuing to be a fertile ground for illegal activities.

3. Description of the Maritime Surveillance Platform

3.1 System Concept & Vision

Border-Safe platform is being developed in a continuum perspective to cover the border security of Greece both in the terrestrial and maritime domain, in an open architecture and with prospect to be expanded in the future, over the entire national border space. However, for the purposes, of designing and development, in the frame of the project, it will be focused over the Eastern Aegean Sea and Evros Region.

Telecommunication technologies: To support Border Safe border security services, the telecommunication network is based on (a) space communications broadcast techniques, using the Digital Video Broadcasting (DVB) standard and Single Channel Per Carrier (SCPC) transmission mode, (b) mobile communication in a local area scale if available through Global System for Mobile Communications (GSM) based transmission mode and (c) on terrestrial communication using any Internet Protocol (IP) based wired connection.

Secure Operational Interface: Several applications will be integrated into the system including - Video tool for UCB - Video conferencing, which is a real time multimedia application for conferencing over IP internet. The video conferencing and (visual and thermal) camera data reception is designed with a flexible and extensible architecture to support heterogeneous environments and configurations. Real time feed will also be able to be transmitted to the border control units of the Border-Safe solution at their mobile devices (pdas, mobiles, tablets).

Audio conferencing and streaming applications allow users to participate in audio conferences over network. These can be between two participants directly, or between groups of participants on a common group. This functionality requires no special user (patrol, command unit) configuration for point-to point communication, just a network connection and a soundcard or a respective mobile phone enabled device (GSM or satellite).

For irregular border crossing analysis or patrol crisis situation management all parties involved are called to assist in delivering effective solutions (command, patrol, experts, and political supervisors). They are called on the command center premises and they operate through the Border-Safe system. Different applications are stored into two different displays for ease of use.

The main purpose of the generic interface is to launch applications and services used in the Border-Safe project for collaboration and communication between the border sea and land units. The main characteristics of this application should be.

- Support for all platforms used in the Border-Safe project (PC, mobile and tablet devices).

- To accommodate this feature, platform independent technologies like internet technologies have been used for the development of the system.

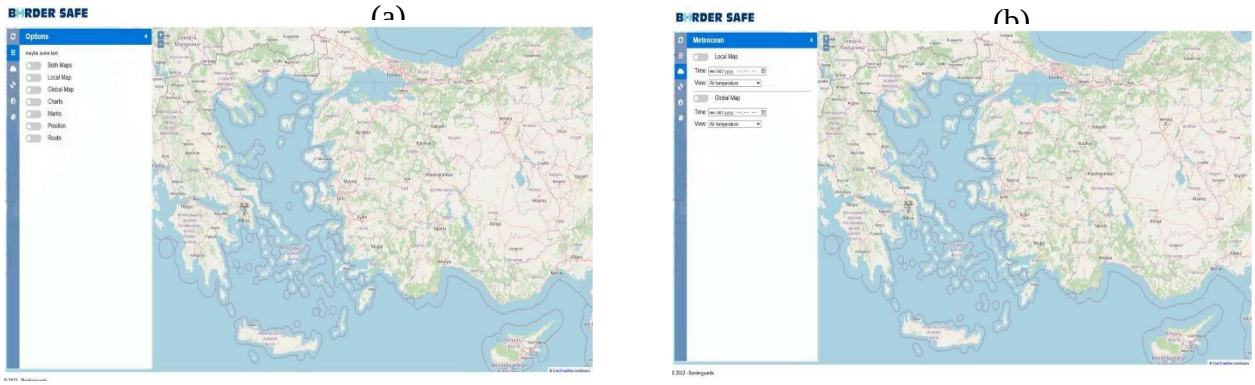

Figure 3. a) Map type selection (left), b) Meteorological data processing/visualization options (right)

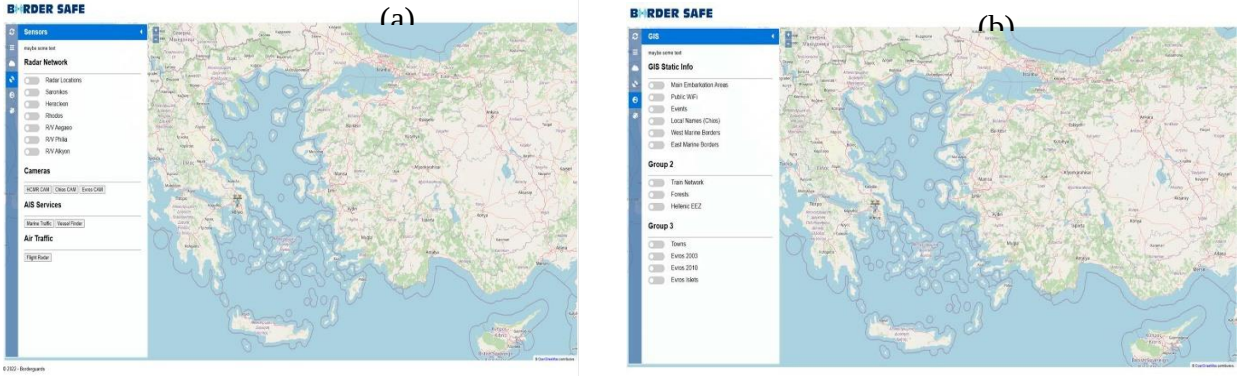

Figure 4. a) Data processing/visualization options from radars, cameras and AIS services (left), b) GIS geospatial data processing/visualization options (right)

Figure 5. a) Satellite data processing/visualization options.

3.2 Technical Description

Border Safe platform covers a wide range of functions, mainly interoperable with advanced technology systems, in order to display complex geographical information. The core of the system is the online GIS (Geographic Information System) database to provide static, dynamic, and real-time information. Earth observation (satellite imagery), georeferenced imagery and analysis are included as part of the overall performance.

The system can also connect to existing available infrastructure services and sensors (e.g. AIS, LRIT, VTS, radar, cameras, weather stations, etc.) and other available monitoring sensors (mobile or fixed IR and thermal sensors, etc.). It is therefore an open architecture system where all sensors can be

connected to detect data, information, alarms, and hazards, either in real time or near real time, to support decision making. Additionally, it enables alerts to be detected, and real-time decisions will be made for local patrols, emergencies and other risk issues that affect border security decisions. Available information can be relayed by two-way communication with local patrols, ships, and other relevant personnel. The architecture of the system is such that it allows the connection of any sensor (radar, AIS, fixed camera, drones, etc.) so that any arrangement of any number of sensors is possible at any time. Figures 3, 4 and 5 show the main functions/interfaces of the platform. Google maps are used as the main cartographic background.

A key element of the developed system is the real-time radar image transmission (Fig. 6a). This allows independent perception of shipping traffic so that potentially suspicious vessels that do not comply with the obligation to transmit an AIS signal can be detected. Through the "Sensor" tool, users can display the green menu, where they can choose the sensor they want to view in the system interface (Fig. 6a).

In this phase of system development, the radar image is experimentally obtained only from the Saronic Gulf, through a radar installed at HCMR (Hellenic Centre for Marine Research) central facilities in Anavyssos (Greece). It is a simple navigation radar, (FURUNO type), whose signals are channeled to the internet through independent digitization. This type, in combination with any other type of radar (e.g. more accurate), it can also be placed in other coastal locations. Thus, this original and alternative system can be systematically expanded and extend the surveillance coverage of marine areas with more sites.

The system also provides the options to display AIS information, either from an independent receiver (e.g. installed at the radar site) or from other providers (e.g. Marine Traffic, Vessel Finder, etc.) (Fig. 6b). Display options are also completed by displaying real-time images from cameras of any type (Fig.6c).

Figure 3. a) Map type selection (left), b) Meteorological data processing/visualization options (right)

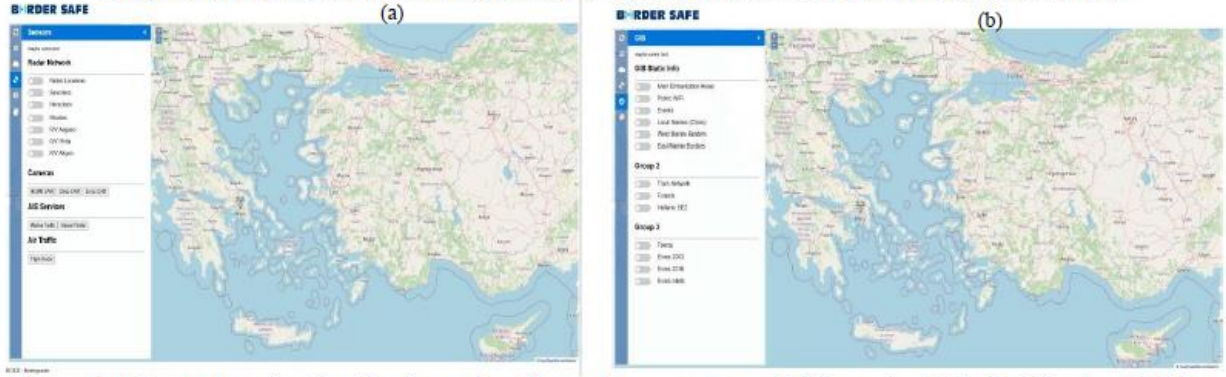

Figure 4. a) Data processing/visualization options from radars, cameras and AIS services (left), b) GIS geospatial data processing/visualization options (right)

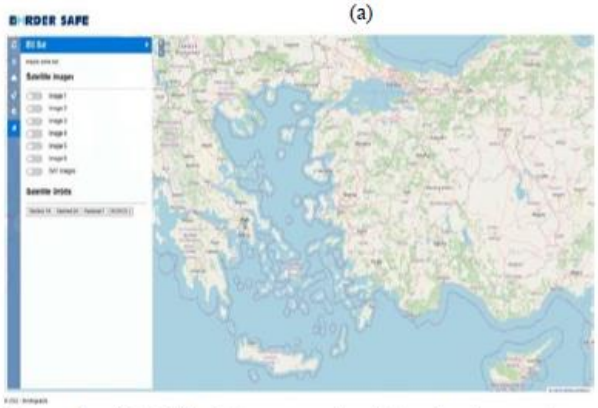

Figure 5. a) Satellite data processing/visualization options.

The system is simple in its design to allow for continuous improvements and additions. It is also designed to operate autonomously, without dependencies on special commercial softwares, so that periodic upgrades and additional costs are required. Most of it is based on open source software, e.g. the central server runs in the freely available UNIX environment and implements industry standard OGC (Open Geospatial Consortium) protocols such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS) for sharing geospatial data [10]. It has a user-friendly interface and no specialized computer skills are required. Authorized users will be able through the interface to import, search, edit and export data, as well as import and export metadata using the Keyhole Markup Language (KML) coding standard, so that metadata can been transferred among systems of different suppliers. KML is complimentary to most OGC standards, including GML (Geography Markup Language), WFS and WMS [11].

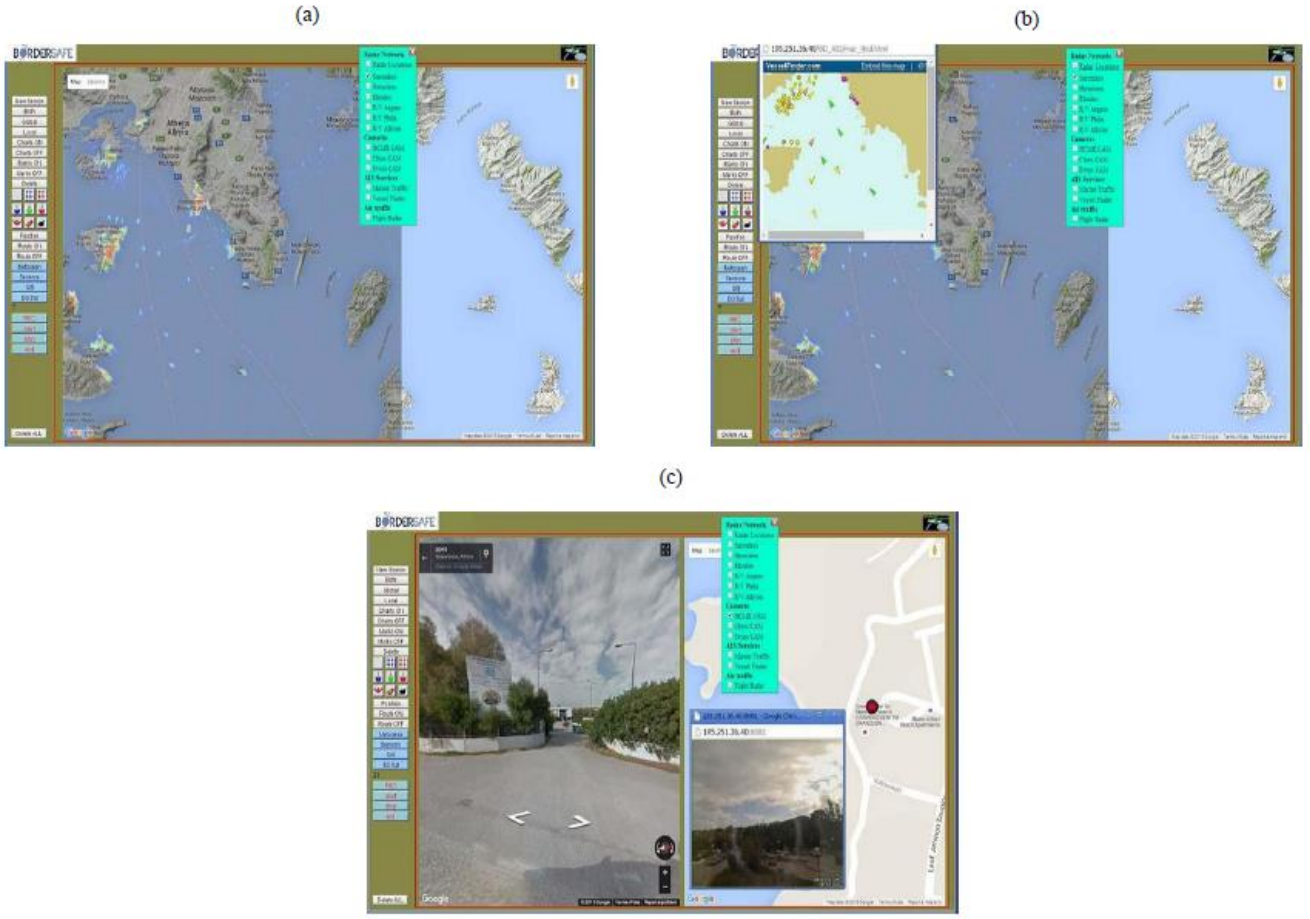

Figure 6. The Border Safe interface: a) Real-time radar image from the Saronic Gulf (left), b) Real-time radar image and AIS information from Vessel Finder (right), c) Real-time image from a camera placed at the entrance of the HCMR facilities (center).

It is based on Service Oriented Architecture (SOA) principles [12]. More specifically, the subsystems that constitute the platform can interoperate through web services and share their information with other subsystems. For example, the meteorological station data sharing subsystem can receive data via API (Application Programming Interface) from various meteorological stations but also send processed data from Border Safe to meteorological centers, provided that they can interoperate through their own APIs with the Border Safe API. The term API defines the set of web services than an application uses to interoperate with other applications [13]. The Border Safe API consists of web services per subsystem and will be developed as a ReST API that will use JSON (JavaScript Object Notation) format to transfer information.

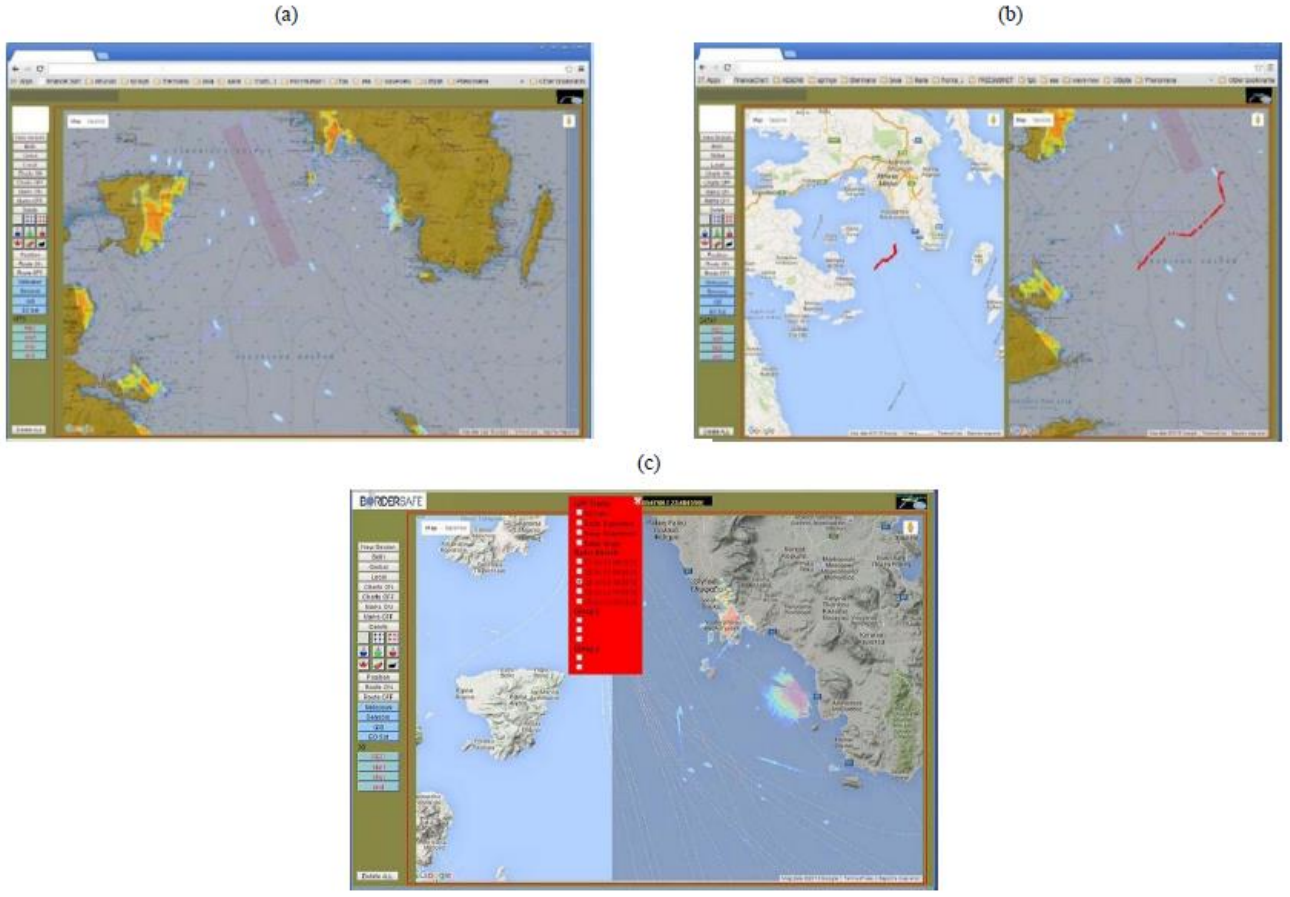

Figure 7. a) Radar image on nautical chart background (left), b) Course display option (right), c) Radar image playback & Aircraft movement through FlightRadar24 app (center).

The system administrator can manage users of the database, in particular, create new users or groups of users and assign them access rights, as well as modify data or rights of a user or group of users. Finally, regular backups are provided through a scheduled process to ensure proper system functioning in case of error (e.g. cyberattack, etc.).

3.3 Additions and Improvements

The extensibility of the system, which was also the strategic goal of the platform, as well as the other visualization options it provides, make it a central core, to which other functions can be added or connected. Such an example is the Decision Support System, through communication and information display, between surveillance and patrol units.

As already mentioned, the system is simple in its design to allow for continuous improvements and additions. These features allow easy adaptation to user requirements, as well as modular attachment of new functions. Such functions include the option to display nautical charts as a cartographic background (in progress) (Figure 7a). This function is activated through the "Charts On" tool on the left of the screen. By bringing the cursor over the map display (right) and using the "Charts On" tool, users can display the local nautical chart of an area. Figure 7b shows the course display option, in the case that a user is in motion (e.g. boat) and the device being used (e.g. laptop, tablet, etc.) supports GPS location. This function is activated and deactivated through the "Route On" and "Route OFF" tool respectively on the left of the screen.

A similar, but more complex function was also developed for the case of radar images. Thus, users can record and replay for review all maritime activity of the surveillance area as captured by the radar sensor and saved on digital devices. It should be noted that due to the large volume of data produced by this function, it is necessary to have sufficient capacity for archiving radar images (e.g. Universal Serial Bus-USB, Hard Disk Drive-HDD, etc.). Figure 7c shows such a snapshot from the Saronic Gulf. This function is activated by users, through "Rec" tool on the left of the main screen. Finally, the option to

monitor the movement of aircrafts, through the FlightRadar24 app, was also integrated into the platform (Figure 7c).

4. Conclusions

This paper presented an innovative maritime surveillance platform that gathers the overall picture of the maritime domain into a single platform, with the aim of finding alternative affordable options, capable of delivering fast and low-cost reliable solutions, to meet the overriding needs of the national maritime surveillance. Existing surveillance systems (e.g. VTS, VTMIS, AIS, etc.) meet some of the requirements of user needs, while also facing maintenance issues, but remain (some of them) operational. The border control process should come from a system not only of surveillance and control but also of identification.

This function is very important for making the right decisions as the system gathers many sources of information. The system is simple in its design to allow for continuous improvements and additions. It is also designed to operate autonomously, without dependencies on special commercial softwares, so that periodic upgrades and additional costs are required.

The Border Safe platform will be developed in two versions: Master platform (full version) for national authorities and organizations and Specific platform with several application for regional authorities etc. Through Border Safe platform, it is expected that a large group of people, such as national, regional and local authorities (e.g. Port Authorities, Coast Guard, Armed Forces, Fire Service, Local Government Organizations, etc.), scientists, decision-makers and management as well as other involved groups will have access to high-resolution and easy-to-understand geospatial data for continuous tracking of terrestrial and maritime objects in their area of responsibility.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Beyond Text: The Photo-Essay as an Innovative Visual Research Method

Abstract:

This paper centers on the application of visual research methods in higher education, specifically focusing on a practical implementation at the University of the Aegean in Mytilene, Greece. The research undertaking involved experimentation with students from the Department of Social Anthropology, exploring the Photo-essay as a distinct multimodal approach within the field of anthropology (Choi et al., 2019). Through a process of reflective analysis, it becomes evident that this endeavor has expanded our understanding of the potential applications of visual research methods in the digital era. The semester-long Visual Anthropology course was structured systematically, delving into the study of images and their poetics, perceiving both still and moving images as acts of representation (Hall, 1997). The context encompassed a comprehensive exploration of both theoretical principles and practical techniques within the field. Particular emphasis was placed on the Photo-essay. Towards the conclusion of the semester, students were encouraged to actively engage as creators of visual texts, enabling them to assume the dual role of researchers and visual creators. The resulting works were presented within the classroom setting, leading to fruitful discussions and exchanges. Notably, select works were submitted to the esteemed scientific journal "Cultural Anthropology" under the category of Writing with Light, administered by the American Anthropological Association.

Keywords: visual literacy, visual anthropology, photo- essay, research method, pedagogical tool

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1. Introduction: The Place / The Time

The presentation focuses on the use of visual methods of research in higher education, through a practical application of Photo-essay. More specifically, we experimented with students at the Department of Social Anthropology, on the Photo-essay as a distinctly multimodal form of anthropology (Choi et al 2019). Firstly, I wish to outline some background. Mytilene is the capital of Lesvos, a Greek island in the northeastern Aegean Sea. Lesvos is often called Mytilene in Greece, after its capital. From 2015 the Island has been a Hot Spot during refugee crisis. Photographer Giannis Behrakis illustrated this phenomenon in an iconic way and was awarded the Pulitzer Prize for their photographic coverage of the refugee crisis.

In the echo of all those were happening in the island I undertook to teach the subject of Visual Anthropology, a course that was to be taught for the first time at the Dept. of Social Anthropology in the University of the Aegean. In this context, I found myself wondering what does it mean to teach anthropology and especially Visual anthropology in these times? The course of Visual Anthropology dealed systematically with the study of image and its poetics seeing the image -either it is still or moving- as a practice of representation (Hall 1997). Photographs have developed to be an embedded part of daily visual culture (Langmann & Pick 2018). We talked a lot about the image and its power and political aspects. I took this course for to be taught for the first time as a theoretical module. But I soon realize that I have to turn it to more practical ways, if I want to suggest ways of seeing to my students.

2. The Method

During the semester, the theory and practices of the field were presented. A focus on Photo-essay was given. At the end of the semester, students were called on to take action and become themselves creators of visual texts. Examples of Photo- essays were presented during the class and detailed instructions were given on the method. Students were free to decide their subject and to work free to choose how to work (collaborative or individual). As students entered the field, they became researchers and at the same time visual creators.

Let us commence by establishing a foundational understanding. What is a Photo essay? Wikipedia defines photo-essay as a form of visual storytelling, a way to present a narrative through a series of images. A great photo essay is powerful, able to evoke emotion and understanding without using words. A photo essay delivers a story using a series of photographs.

Pink supports that no visual image or practice is essentially ethnographic by nature. Accordingly, it is claimed, “an anthropological photograph is any photograph from wich an anthropologist could gain useful, meaningful visual information” (2007, p. 66).

To review the photo-essays made by students we adopted a rubric suggested by the scientific journal *Cultural Anthropology* (2016) through the guidelines for submissions to their journal under the section of Photo-essays. We did that in order to adopt a valid way of work. Also, we would like to be able to submit our works in order to be evaluated under real circumstances. The criteria are presented below. Photo-essays had to use no more than fifteen photos and captions had to be limited to 200 words each.

Conceptual Guidelines

- What is the contribution to scholarly knowledge?
- Is there a strong argument and narrative?
- Is there a theory of the image deployed?
- Do text and image work as accomplices?
- Does the photo-essay show a keen understanding of image ethics?

Categories of Evaluation

- Contribution to Anthropological Knowledge
- Argument and Narrative
- Production Quality and Theory of the Image
- Image–Text Relationship
- Ethics and Politics of Representation

3. Students' Work

At the end of the semester, after the preparation that was done within the course, students have to present their photo-essays. Students were strongly suggested to send a sample of their work in the early stages and before presentation, so that there is time for any necessary revisions. All the works were presented in class, followed by productive discussions. It was a very dynamic procedure. Finally, after revision, a couple of them were submitted to the scientific journal "Cultural Anthropology" (American Anthropological Association) in the category Writing With Light. This submission was for the students, not only a motivation, but also a chance to have a realistic critique with high academic standards. Their photo-essays had to meet the requirements for the assignment in terms of content, format, and length.

The paper explores an assortment of notable elements extracted from the students' photo-essays, thereby presenting a segment of their endeavors.

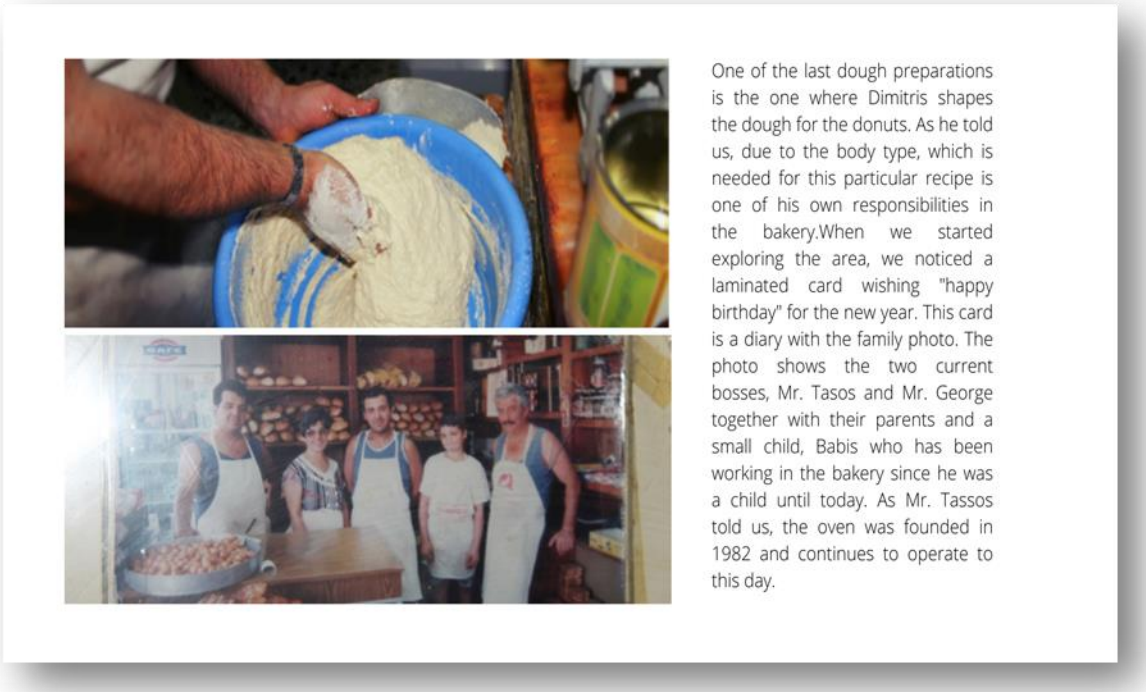

Fig.1. Oskar bakery in Mytilene (Marina Arabatzidou, Angeliki Bani, Popi Rina)

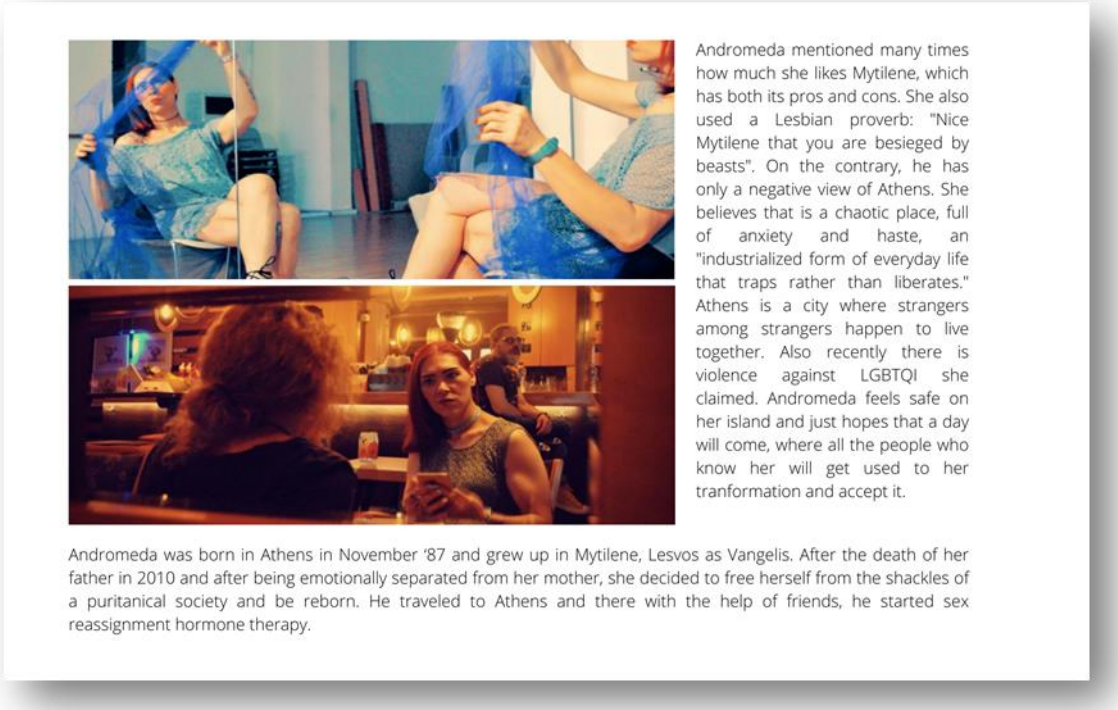

Fig.2. Andromeda: The story of a trans woman in Lesvos (Melissanthi Ntagiou)

Fig.3. Easter with the Argyropoulos family (Telidou Chrysi, Fintanidi Alexandra)

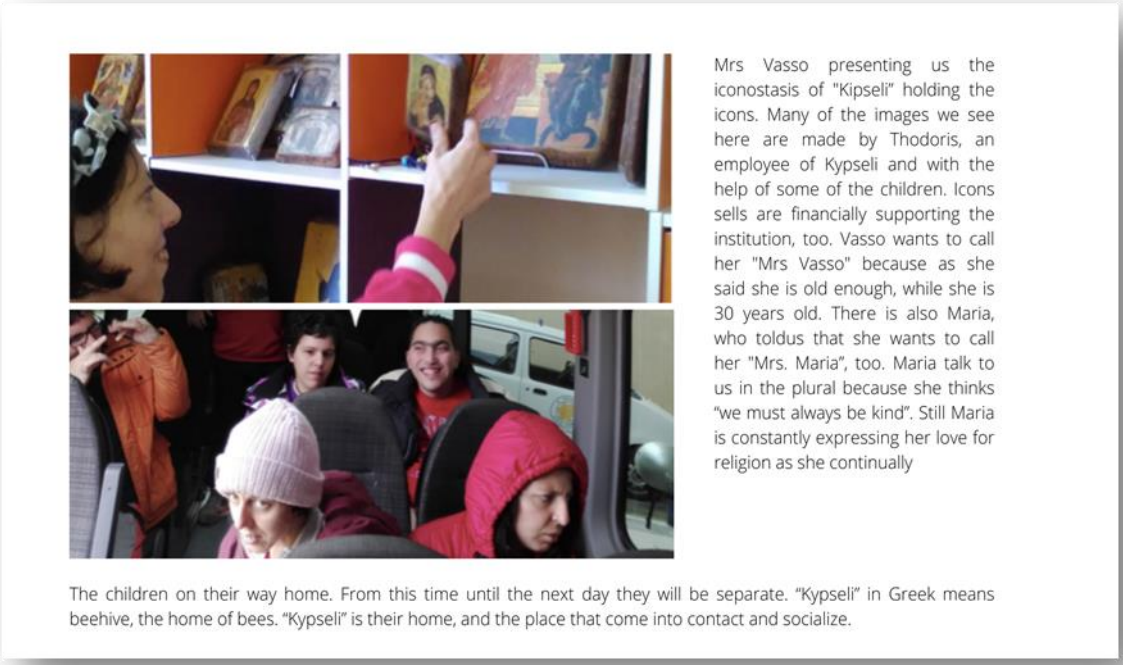

Fig.4. Life in a daily care center in Mytilene (Kompothanasis Ioannis,Letzaki Fani)

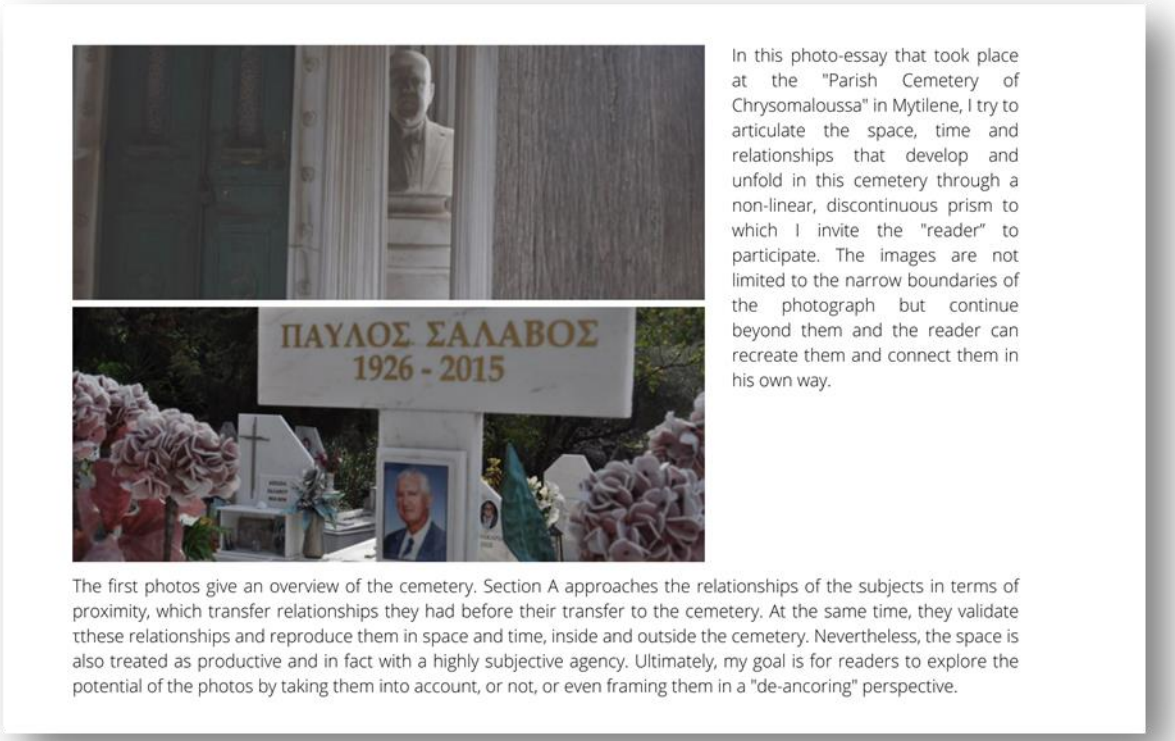

Fig.5. An unexpected place (Leonidas Eleftheriades)

4. Reflective Discussion

The photo-essays provided the opportunity for extended conversations among us about a series of specific concerns regarding the relation between image and text in the digital age (Choi 2019). As a consequence, during these conversations:

- Students reviewed each other's photo essays using the rubric and provide feedback
- Students gave and received feedback that was focused and constructive
- Students self-assessed their work and develop a plan for further revision or editing

From my standpoint, I derived immense satisfaction from the active engagement of the students in this project. Evidently, the students displayed unwavering dedication towards our shared objectives. They demonstrated a keen inclination to acquire information encompassing both technical and theoretical aspects, with the intention of enhancing their creative output. It was apparent that they perceived themselves as active creators, assuming a sense of accountability akin to conducting empirical research in the field.

Furthermore, as students evaluating the process, made remarkable interpretative comments and observations. To begin with, students discuss about numerous occasions, that the individuals themselves took the initiative to intervene, explicitly signaling to them the pivotal moments they deemed significant for photographic documentation.

> *"When we revealed to the family members that they would be the subjects of the work, we faced positive reactions. Many times, the individual themselves made their intervention, wanting to indicate to us which moments were important to be photographed. For example, Mr. Alekos mentioned that we had to use video-camera, in order to present in detail some process without losing any part of it. Also, at the end of each day where the photos were sent to Ms. Telidou for discussion, they were often presented to family members for further discussion".*

In the second place, the same students, as they go back to the procedure of taking photos, deepen their thoughts on gendered meanings.

> *"The way in which practices are divided by gender and age, but also the way in which space was divided quickly became clear for us. For example, the men were active outside the yard, while the women at the same time were mostly inside the house".*

In the same direction, a couple of students note the power relations in the field and how their photo essay gave them broader perspective.

> *"This work helped us to understand and discover new things about this place. The lens has thus given us another dimension, both close and distant, to understand the actions and attitudes of people with disabilities. (...) The camera was the means for us to see power relations within the place".*

Other students bring on some of their difficulties in the discussion revealing how they manage to make the final editing of their photo-essay. These difficulties may refer to the research in the field and the shooting process, or the editing of the final product.

> *"The total number of photos we took were 1,200 and the only problem we had was to select fifteen of them for the final presentation. During taking photos, we tried to set some criteria in order to create a logical order in the photos. Some of them are to follow a series, not to constantly show the same set, as well as to highlight the relationship of the staff".*

> *"The process of photographing was difficult. We were having difficulty shooting as the subjects were turning and look directly at the camera. As a result, the whole scene seemed to be set. For this reason, we decided to take pictures while everyone was busy".*

As evident from these excerpts, the students demonstrated a profound contemplation from various angles, engaging in thoughtful reflections on their photographic endeavors during the fieldwork. They meticulously evaluated their experiences, discerning both successful and unsuccessful aspects, while also formulating ideas regarding alternative approaches they would have adopted given the opportunity.

5. Pedagogy, Knowledge, Experimentation

Following an enriching phase of exploration and active involvement with the visual field, the examination revealed that these visual recordings served dual purposes: they served as valuable research tools and facilitated experiential documentation and reflective exercises (Banks, 2007).

The aforementioned analysis highlights the significance of photo-essays, which offer a pivotal avenue for reassessing the intricate dynamic between words and images. Renowned for its narrative qualities, the Photo-essay is especially useful in reconsidering the relationship between words and images in photographic storytelling, as well as efforts to generate innovative anthropological knowledge with the capacity to go beyond storytelling (Society for Visual Anthropology, 2019). In addition, Photo-essay has a potential to generate insights focused on issues of mediation and representation, as well as methodological questions with the potential to shift how anthropologists conceive of the discipline itself (Society for Visual Anthropology, 2019).

For example, how does photography produce different types of knowledge than text and/or film? What criteria might we need to interrogate and evaluate each of these forms of multimodal study? Photo-essay can be a part of a broader set of questions about the

relationship between forms of scholarly work and knowledge production (Society for Visual Anthropology, 2019). This opens new understandings to the roles of the researcher and participant and as Langmann & Pick claim it is significant who enfolds photographs and who unfolds and interprets them (2018).

It is crucial to reiterate the significance of fostering opportunities for student autonomy when engaging in authentic tasks. In the realm of creating a photo-essay, there are several avenues through which student choice can be nurtured. Students can exercise their autonomy by selecting the topic, defining the message they wish to convey, and establishing their position. They possess the agency to choose the specific photographs and accompanying text to incorporate, as well as determining the intended audience and purpose of their essay. Furthermore, students have the freedom to make deliberate decisions regarding the layout and sequencing of the photos, effectively crafting a narrative that effectively communicates their perspective.

6. A Broader Discussion

Within the context of nearing the conclusion of this endeavor, I experienced a sense of triumph as I witnessed a remarkable evolution taking place. Throughout our discussions, I had the privilege of observing a profound transformation in the students, as they transitioned into researchers, creators, and discerning critics of their own work. Admittedly, while the quality of the photographs captured by the students was not consistently impeccable, it is imperative to acknowledge that it constituted their initial foray into independently employing visual methods.

Drawing upon this enriching experience, several pivotal theoretical considerations come to the fore, warranting particular attention. These considerations are encapsulated in the form of the following thought-provoking questions that merit highlighting.

- Do Visual Anthropology and Visual Literacy meet?

Visual anthropology is both the practice of anthropology through a visual medium and the study of visual phenomena in culture and society. While most disciplines traditionally communicate through the written word, visual anthropologists are particularly interested in communicating anthropological data in new, visual ways. Visual literacy is defined as a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media. Visual literacy skills equip a learner to understand and analyze the contextual, cultural, ethical, aesthetic, intellectual, and technical components involved in the production and use of visual materials. A visually literate individual is both a critical consumer of visual media and a competent contributor to a body of shared knowledge and culture (Visual Literacy Standards Task Force, ACRL, 2011). In short, a person who does Visual Anthropology and uses visual research methods, has to equip all the above skills in a high level.

- How is the research method of Photo-essay related to critical thinking and in what ways can help students read, understand, analyze and produce authentic visual texts?

Canete argued that images are not just a ‘social artefact’, rather is a product of the complex power relations between the subjective content of the image, the viewer, and the photographer (Mullick, et all 2019). Through the procedure of photo shooting, selecting photos and captioning, students deeply engaged with these concepts. The photo-essay provides a critical opportunity for reevaluating the word – image relationship. The photo-essay is especially useful in reconsidering the relationship between words and images in photographic

storytelling, as well as efforts to generate innovative anthropological knowledge with the capacity to go beyond storytelling. (Society for Visual Anthropology, 2019).

In our inquiry into the interconnections between various forms of scholarly work and the generation of knowledge, we delved into the enduring significance of the photo-essay. Our observations of the students' photo-essays have demonstrated its potential to serve as a highly valuable research tool within the realm of education.

- Can we consider Photo-essay a flexible pedagogical tool (Wesolowski 2013) in order to create a more interactive classroom and participate in engaging conversations (Rice & Lauren 2013)? To what extent teaching practices could draw upon this method?

In addition to its capacity for reevaluating the intricate relationship between words and images, the photo-essay offers abundant opportunities for student autonomy. In essence, the photo-essay revolves around the act of selection. Students are tasked with choosing the central theme, identifying the opportune moments for capturing compelling shots, and carefully curating a narrative from a multitude of photographs. This authentic undertaking generates a genuine sense of devotion and enthusiasm among the students as they actively engage in the process. Consequently, the photo-essay emerges as an exemplary teaching practice—a versatile pedagogical tool that fosters flexibility and adaptability in the educational setting.

- Visual methods, such as Photo-essay, would be beneficial if used in fields other than anthropology?

I am firmly persuaded that the assertion regarding the photo-essay's nature as a flexible pedagogical tool extends beyond mere conjecture. Indeed, it holds immense potential for practical application within undergraduate and postgraduate programs dedicated to nurturing future educators, particularly in their pursuit of fostering a comprehensive and profound cultural appreciation of the visual medium. This prospect has instilled a particular sense of interest within me, leading me to identify it as a prospective research endeavor for the forthcoming period.

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Externalities of the COVID-19 Pandemic and the Government's Intervention

Abstract:
In 2020, the novel coronavirus COVID-19 epidemic that first broke out in China has been spreading worldwide and has caused widespread loss of life. It is also recognized that the pandemic triggered the most serious economic crisis, because of the restrictive measures imposed to prevent the rapid spread of the virus. The health externalities that arise when social and economic interactions transmit infectious diseases are analyzed. Market failures can be corrected through governments' policies such as health guidelines and rules (e.g. wearing masks, social distancing, lockdowns - quarantine rules, and so on) and strategies that have to deal with non-health issues arising. In this direction, restrictive measures against the spread of the disease and its direct negative externalities were initiated. Studies at the macroeconomic level also highlight the indirect negative externalities of the epidemic's effects on the economy. The double exogenous shock to supply and demand of the COVID-19 pandemic has affected the real economy and caused large economic losses. These developments were reflected mainly in the dramatic decline in global GDP and international trade. Faced with the weakness of the market economy and the price mechanism, the States activated intervention measures to implement the best economic policy, which however led to an increase in the budget deficit and debt and created new challenges. A global response is clearly the best means to counter an emergency public health threat.

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1. Introduction

The COVID-19 pandemic that broke out in 2020 was a global health crisis that led to an increase in mortality with significant loss of life and morbidity, illness that prevents work. The coronavirus - COVID-19 epidemic first appeared in the Wuhan region of China, spread rapidly around the world. So if we take into account the rise of China's importance in the globalized economy today and the greater interdependence in the world economy, shocks to other countries were transmitted with particularly extensive consequences. China's economic slowdown with interruptions to production, also reflected in the decline in GDP growth, gradually spread to other countries through disruptions of global supply chains. Thus, the output of China-dependent States in terms of imports and transport (land, sea, air) shrank.

The public health crisis resulted in a deep economic depression that surpassed even the Great Depression of the 1930s. It is characterized by negative externalities with direct and indirect costs to the economy and society in general. In terms of direct health effects, on the one hand, in a context of information asymmetry, some individual behaviors increase the risk of infecting other people more per interaction than alternative behaviors. The pandemic, on the other hand, causes macroeconomic externalities that are reflected in the significant decline in global GDP. Activity in many sectors has been completely halted and mobility has been restricted.

To limit the spread of the coronavirus epidemic and save human lives, most governments worldwide reacted extremely quickly to the crisis. Restrictive measures and economic policies were designed to enable States to address weaknesses in the market economy and the price mechanism. Pandemic-related measures have contributed to success in slowing the spread of infections, limiting the number of deaths, supporting companies, and maintaining essential services and incomes. In general, they have prevented the economy from collapsing. However, short-term macroeconomic disruptions and job losses have persisted.

For this purpose, at first sight, the direct costs associated with health externalities of the COVID-19 pandemic dimensions are examined: direct impact in terms of health and lives lost. Then, the indirect costs related to the macroeconomic externalities of the pandemic are analyzed as well as the fiscal policy of the States to deal with dysfunctional markets and to stimulate economic activity.

2. The direct costs of a health crisis: the health externalities of the COVID-19 pandemic

2.1 The social costs and dimensions of the COVID-19 Pandemic

The new strain of coronavirus (COVID-19) was first detected in China, in the city of Wuhan, and gradually spread to Latin America's Mexico and Brazil, India, Russia, Europe, South Africa, and the United States, rapidly gaining dimensions of a global pandemic. In this context, the outbreak of the COVID-19 epidemic at the international level was declared by the World Health Organization (WHO) as a public health emergency, while in March 2020 it was characterized as a pandemic. It is noted that a pandemic is a disease epidemic that has spread across a large region usually affecting people on a worldwide scale within a limited time. Its characteristic is the rapid spread over a large area, which can even exceed the country's borders and acquire a global dimension. A pandemic is not only deadly, but it is mainly highly infectious and contagious, unlike serious diseases such as cardiovascular diseases or malignant diseases. Examples of pandemics include tuberculosis, smallpox, and the plague of earlier times, as well as HIV/AIDS and the COVID-19 pandemic. According to WHO data, the disease COVID-19 is caused by a new strain of coronavirus, SARS-CoV-2, and is

primarily transmitted between people through respiratory droplets and contact routes (World Health Organization 2020, Sun *et al.* 2020).

The outbreak of the pandemic had direct demographic effects on modern globalized societies. In addition, it has had a direct cost on human lives by increasing mortality (death - people who die) as well as direct negative consequences on human health by increasing morbidity (disability - people unable to work for a period) (Warwick and Roshen 2020). In 2022, the number of confirmed cases of COVID-19 worldwide exceeded half a million citizens, while the number of deaths reached 6,523,438. However, there were also several asymptomatic patients.

2.2 A brief history of the World's deadliest pandemics and Epidemics

The current juncture is not the only one in terms of the emergence of pandemics (Ferguson *et al*. 2020, Frith 2012). Great pandemics have impacted the world on a global scale. They have resulted in significant death tolls and major social disruption. Among them, the Spanish flu of 1918-19, "*the deadliest plague in history*," with its extreme severity and gravity of clinical symptoms, continues to puzzle researchers to this day. The influenza virus is by far more contagious than HIV. It appears that the COVID-19 virus is also very contagious. Table 1 below provides a historical list of the world's deadliest epidemics and pandemics caused by infectious diseases.

Table 1. Notable pandemics diseases in history with at least 1 million deaths

Epidemics and Pandemics 	Date	Death toll
Antonine Plague	165 - 180	5 - 10 million
Plague of Justinian	541 - 549	15 - 100 million
Japanese Smallpox epidemic	735 - 737	2 million
Black Death - Rats	1346 - 1353	75 - 200 million
Italian Plague	1629 - 1631	1 million
Third Plague	1855	12 million
Russian Flu or Russian influenza	1889 - 1890	1 million
Cholera Pandemic (1-6)*	1817 - 1923	1 million
Spanish Flu - Influenza A/H_1N_1	1918 - 1920	17 - 100 million
Asian Flu	1957 - 1958	1.1 - million
Hong Kong Flu	1968 - 1970	1 - 4 million
HIV/AIDS pandemic	1981 - present	40.1 million (2021)
COVID pandemic	**2019 - present**	**6.7 - 28.3** million (December 2022)

Source: https://en.wikipedia.org/wiki/List_of_epidemics

(*)There have been other cholera epidemics with the lower death toll, such as 1826-1837, 1846-1860, 1863-1875, 1881-1896, 1899-1923, and 1961-1875 Cholera Pandemic.

More specifically, the Human Immunodeficiency Virus (HIV) is the virus that causes the Acquired Immune Deficiency Syndrome (AIDS) ("WHO HIV/AIDS Data and Statistics"). The virus was first detected in Africa and spread to the US. It was considered one of the world's deadliest pandemics with over 40 million victims since 1981. This infectious disease spread via blood personal and sexual contact. As the virus spreads from person to person

among those in close contact, preventive health education and measures combined with the implementation of new treatments, have helped reduce the infection rate. In our time, the rate of infections has stabilized thanks to implementing wide-ranging strategies.

The onset of the virus of the COVID-19 epidemic, initially in China, and gradually in the rest of the countries, can be sudden and unexpected, while until 2020 there was still no vaccine to deal with it. The current death toll is 6,523,438. Elderly people over 60, as well as people with underlying diseases, are at serious risk of developing the harmful disease. Among the most effective tactics to deal with the health crisis were hand washing and physical and social distancing, while generally mandatory measures by governments (masks, home isolation-quarantine, vaccines), closure of schools, businesses, and public spaces, and other preventive measures were also ways to reduce risk of symptoms.

2.3 COVID-19 and infectious disease externalities

The COVID-19 pandemic is a typical example of negative externalities. Negative externalities arise when social and economic interactions transmit infectious diseases such as COVID-19. The virus that causes COVID-19, spreads from an infected person to others via personal contact, coughing, sneezing, and breathing, with transmission by respiratory droplets and aerosols. Certain behaviors increase others' infection risk more per interaction than alternative behaviors, for instance, interacting without wearing a mask or without keeping one's distance versus interacting while wearing a mask or keeping one's distance. Behaviors to comply or not comply with health regulations at the individual level create externalities. Typical examples are social interaction with or without wearing a mask, keeping the required distances, or even isolation (quarantine) or not. Such behaviors are privately cheaper than behaviors that increase others' infection risk less per interaction. Effectively, wearing a mask or keeping a distance is inconvenient (for the distance keeper) compared to not wearing a mask or not keeping a distance. In several cases, non-compliance with the rules is considered less inconvenient or even privately cheaper.

Population exposure and overall health risks are reduced when more of society isolates itself. The differences in the behaviors are determined to a large extent by information asymmetry. For example, a person may be aware of his disease-infection (asymmetry with respect to the other person) or even be unaware of it, especially in the case of being asymptomatic (an even greater asymmetry). Disease contagion creates an externality that is impossible for the free-market economy to deal with through the price mechanism. For example, if one person exposes another person to the virus, the latter incurs a cost not borne by the person who caused it (Stiglitz 2021, Greenwald and Stiglitz 1986). Consequently, the above lack of individual motivation for self-restraint raises other challenges.

3 The indirect cost of a health crisis: macroeconomic externalities of the pandemic

3.1 China: the initial center of the pandemic and the slowing down of the Chinese economy

Activity declined sharply in China, the initial center of the pandemic. With the slowing down of the Chinese economy and interruptions to production, the functioning of global supply chains has been disrupted. China, as an important global economic power, plays an essential role, which consists in the increased dependence of the rest of the States of Asia, Europe, but also the U.S.A., on the orderly operation of its own economy and on the quantity of exported goods and services. Companies dependent upon inputs from China have started experiencing contractions in production. We typically mention the example of the substance paracetamol, an essential "raw material" in the pharmaceutical industry of many European and American companies for which China gathers 60% of the world's production. The contraction in

production has also been felt in other Asian countries that work closely with China through supply chains.

The pandemic has disrupted activities across all countries and has negatively affected global economic growth in 2020. Open economies are more vulnerable to international shocks. Therefore, China's sudden shutdown of the production process, with the closing of factories and the blockade of its ports due to the pandemic, has aggravated and disrupted the production process in the industries of many other countries through the "global value chains". Shocks to other economies were transmitted according to the degree of the countries' exposure to the disease. China's economic slowdown has added to global supply chain disruptions. As for the advanced economies of the euro area, production fell more sharply than in the U.S.A. and Japan, reflecting the more stringent shutdown measures implemented (Warwick and Roshen 2020).

3.2 Supply-side shock: a sudden shrinking of production capacity

The economic recession of 2020 was considered unprecedented in peacetime, deeper even than that of 1929. The imposed emergency measures with business closures led to social distancing and general uncertainty, sharply curtailing business activities. This phenomenon resulted in an increased contraction of the service sector compared to that of the production and trade of goods. For the same reason, the sectors that were hit hardest of all were international trade and investment. Businesses received unexpected and successive "supply shocks", due to the "sudden stop" of activities, as well as the reduction of travel-transportation that facilitated communication with their main suppliers (Pelagidis 2020). Transport being limited and even restricted has further slowed down global economic activities. Unexpected supply-side shocks had upset many businesses, with the closure of "non-essential" activities in particular (bars, cafes, hair salons, etc.) and travel restrictions creating difficulties in operating efficiently and weakening relationships with key suppliers. Businesses have experienced a large and persistent decline in sales and profits during the pandemic recession, especially in the tertiary sector (GSEVEE 2022). Indeed, many businesses are in full or partial shutdown, raising fears related to the lack of essential goods in the future, even amid ongoing health restrictions. Small and medium-sized enterprises in the tertiary service sector took an even harder hit in turnover from the imposed shutdowns, due to their limited inventories. These fears are further justified by the closure of industrial and commercial establishments and administrations as well as by layoffs. This leads to a reduction in the labour factor and thus to a lower production capacity.

The sectoral heterogeneity of the crisis had different effects on productivity. The economic slowdown from the pandemic has had a disparate impact on certain economic sectors, particularly the service sector. Global trade in goods and services shrank by 9.6% in 2020 (IMF), with the tourism and transport sector hardest hit among tertiary sectors. Air traffic has been particularly hard hit and, to a lesser extent, the international traffic of goods. However, several manufacturing sectors have managed to improve their performance despite the pandemic. Amid the COVID-19 pandemic, this progress covered part of the emergency needs and the increased demand for medicines, disinfectants, electrical equipment, and computers. The above development resulted in limited losses in the secondary sector compared to the tertiary sector (Bank of Greece 2021, Mou 2020).

3.3 The demand-side shock: a reduction in household demand

At the same time, the effects of the health crisis on household demand are detected due to the confinement with the imposition of restrictive measures to prevent the spread of infectious diseases. Such measures include the imposition of quarantine, for instance. On the demand side, the recession was observed mainly in consumer goods and services whose exchange

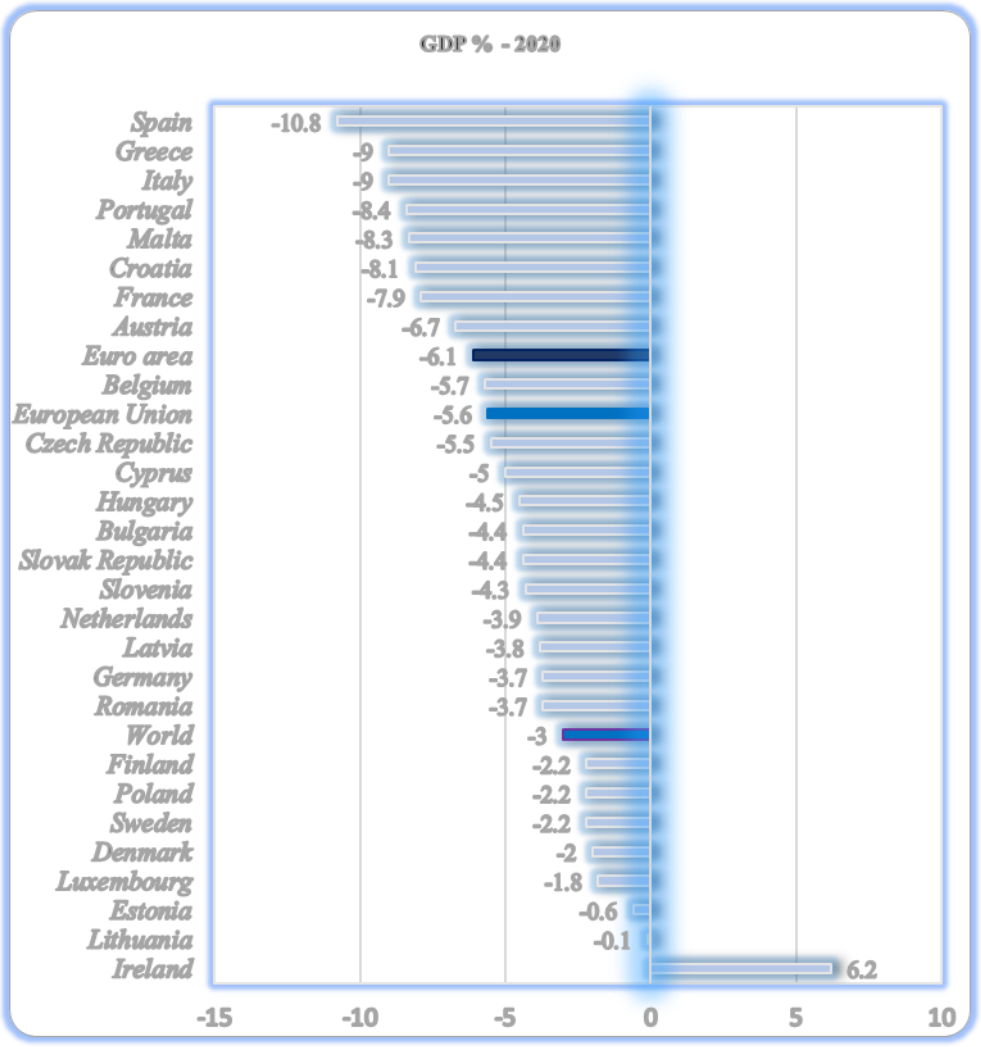
required close contact between producers and consumers (Bank of Greece 2021, Pelagidis 2020). It was mainly the case of the travel and tourism industry. This situation has caused large revenue losses and a severe liquidity shortage for many companies in the world. Small and medium-sized enterprises have been particularly affected. Most importantly, some panic among consumers, losses in purchasing power, the decline in consumer confidence, and rising unemployment have distorted usual consumption patterns and created market anomalies, restricting household consumption and adding to precautionary saving. Studies of the macroeconomic effects of the epidemic found significant effects on economies through large reductions in the consumption of various goods and services. Private consumption fell in 2020 (-7.9%), as a result of cutting spending on services and durable goods. These disturbances also were intensified in the transport, hotel, catering, and leisure sectors.

3.4 A sudden collapse of global activity

To limit the spread of infectious disease restrictive measures were imposed and all of the above has had severe negative impacts on the global economy. The pandemic measures have closed down most of the economy, triggering sharp and sudden contractions in output, spending, and employment. The Great Lockdown has brought the economy into a recession of great dimensions (Mou 2020). The world GDP has contracted significantly by 3 percent. The COVID-19 pandemic worsened the economic situation in 2020 mainly in the countries of the European Union, with the GDP declining by 5.6 percent and even more in the countries of the Eurozone (GDP_{2020}: -6.1%). These declines have been especially deep in Europe and some emerging-market economies[2]. However, the effects on the GDP of the Member States varied by country, depending on the type of government intervention (Figure 1).

[2] India and Indonesia

Figure 1. GDP growth - 2020



Source: IMF (ΔNT) 2022 – World Economic Outlook (October 2022).

The small economic recovery that has begun in Greece was suddenly stopped due to the pandemic, as a result, the real GDP has shrunk dramatically by 9.0% in 2020 (real GDP_{2019}: +1.8% and real GDP_{2020}: -9,0%). Real GDP dropped by approximately the same amount in 2020 in Italy (-9%), Portugal (-8.4%), Croatia (-8.1%), and France (-7.9%). To a less extent, GDP decreased in 2020 in the economies of Germany (-3.7%), Romania (-3.7%), Bulgaria (-4.4%), and Cyprus (-5%). Spain was one of the worst affected Eurozone countries by the coronavirus pandemic. The GDP of Spain shrank by 10.8% in 2020. In contrast, Denmark and other Nordic States such as Sweden and Finland, and Poland suffered a relatively small decrease in GDP compared to the European average (of the order of -2,0% respectively).

The recession in the Eurozone is mainly due to virus-related supply shocks, through the high participation of its States in the disrupted global value chains, but also to demand shocks, due to the particularly strict way of enforcing the mandatory restrictions (Bank of Greece 2021). Among G-7 countries, the United Kingdom has experienced the largest fall in real GDP, of the order of -9.3%, while the GDP shrank to a lesser extent in the U.S.A. (-3.4%) and Japan (-4.6%). The effects of the pandemic also spread to Turkey, where a recession and currency crisis occurred in 2020, but the rate of change of GDP was ultimately positive. As for the strong economies of China and India, which showed leaps and bounds in

the last decade, the former was burdened in 2020 without suffering a recession (GDP_{2020} +2.2% vs. GDP_{2019} +6%), due to the faster normalization of the economic situation in comparison with other countries and its favorable economic policy. In contrast to China, the Indian economy experienced a recession in 2020 (-6.6%) due to looser government intervention.

3.5 The shock to employment and unemployment

With the economy suffering the consequences of the measures against the spread of the virus, many businesses have been forced to underperform or even suspend their activities. This disorganization led to a reduction in the supply and productivity of labour, as well as to the underutilization of production capabilities, and finally the decline of economic activity. The consequences for employment, supply (from the workers' side), and demand for employment (from the employers' side) were immediate.

The pandemic led to job losses in 2020. Total employment fell by 1.2% in 2020, mainly in terms of fixed-term employment contracts. Temporary workers suffered job losses at a higher rate than non-temporary workers. Indicatively, temporary employment decreased in the E.U. (2019: 15.0% and 2020: 13.5%), and among other countries such as Greece (2019: 15.0% and 2020: 13.5%), France (2019: 15.8% and 2020: 14.9%) and Germany (2019: 12.0% and 2020: 10.9%). The pandemic has worsened the labour market and made it fragmented. The duality of the labour market has worsened during the health crisis, affecting more flexible forms of work, such as temporary employment, with young people, lower-skilled workers and women more represented in this category.

The global labour market outlook has deteriorated. The unemployment rate increased in the E.U., from 6.8% in 2019 to 7.2% in 2020. In the countries of the Eurozone in 2020 the unemployment rate was 7.9% and varied between 4.9% in the Netherlands to around 15% in Spain (15.5%) and Greece (16.4%). Outside of the E.U., the unemployment rate was also particularly high in the U.S.A. in 2020 (8.1%), marking a significant increase compared to 2019 (3.7%), while the effects in the United Kingdom (2019: 3.8% and 2020: 4.6%) and in Japan (2019: 2.4% and 2020: 2.8%) were milder.

Furthermore, the Covid-19 crisis has brought changes to the way businesses work and operate. The adoption of new digital technologies has been central to these changes. Key examples include increased working from home and online sales. The adoption of digital technologies led many countries to the expansion of teleworking. However, the application of the remote work model was not always possible in all professions. The expansion of the digital economy, a result of rapid technological developments, has brought about significant structural changes, with a positive effect on some industries, which have flourished, while others have been negatively affected (Nagel 2020). Significant progress in the field of digitization was also made in the public sector and the field of education. This change has also spread to the way businesses operate, which have been modernized and upgraded, while transparency has increased and cyber security has been strengthened. The example of the transformation enabled in Greece by the funds of the Next Generation EU recovery instrument is indicative.

3.6 The impact of the COVID crisis on markets

The pandemic COVID-19 is not only a public health crisis, it has disrupted global activities across all economic sectors and industries. It has also severely affected the global oil and financial markets. The volume of industrial production has fallen sharply due to the virus. This situation led to a total collapse of certain activities linked to tourism and transport, especially air transport. Subsequently, the Demand for crude oil has fallen. This was associated with a sharp fall in investment by oil-producing companies as global oil prices collapsed in February 2020. As a consequence of the above collapse, global financial markets have also been responsive to the changes and global stock indices have plunged. Thus, all COVID-19-related actions initiated by governments and public authorities became imperative.

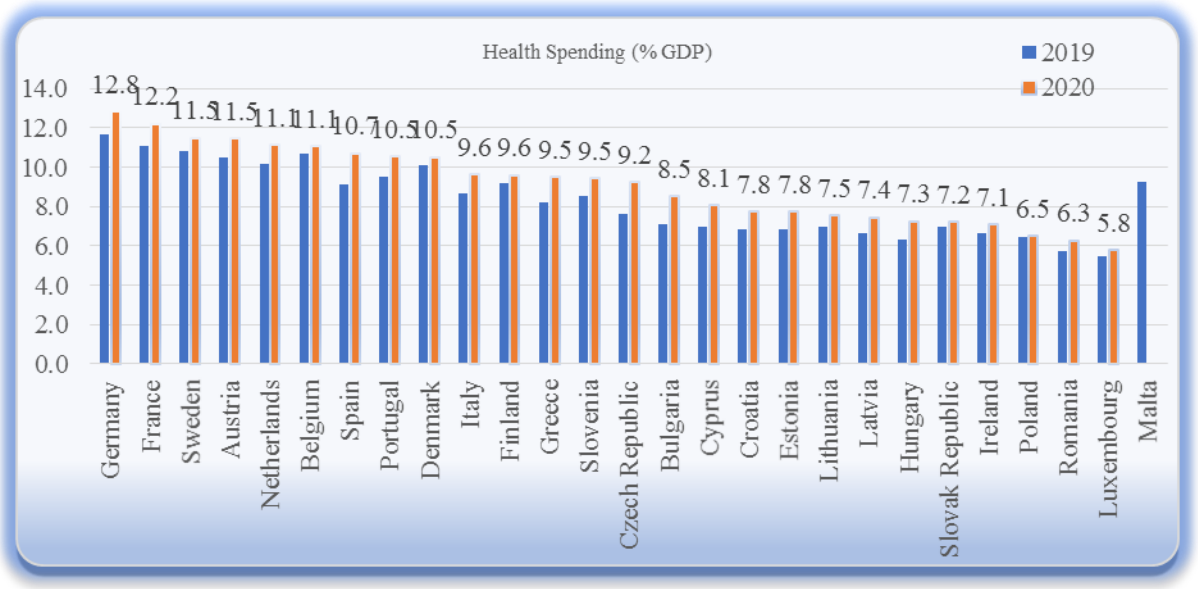
4 Market Failures and fiscal measures for dealing with the COVID-19 Pandemic

4.1 The increase in public expenditure to limit the externality of contamination

As individuals do not internalize the impact of their actions on others and consider the private cost of an additional infection to be less than the actual social cost when in practice the social cost is greater (Bethume and Korinek 2020), the pandemic global health crisis COVID-19 forced the governments of several countries to activate public health measures (Jita *et al*. 2021). The emergency measures stretched the capacity of hospitals and other healthcare sectors, helped to maintain incomes for workers and companies despite the shutdown, and secured private debt on a large scale in some countries.

Figure 2 shows all E.U. Member States increases in health expenditure or spending as a percentage of GDP and as a result of the health measures to deal with the pandemic in 2020. Among the E.U. countries, Germany (12.8%), France (12.2%), Sweden (11.5%), Austria (11.5%), the Netherlands (11.1%), and Belgium (11.1%) had the highest health spending relative to GDP in 2020, followed by countries such as Spain, Portugal, and Denmark with lower percentages of 10.5%. In Greece and Cyprus, health spending amounted to 9.5% and 8.1% of GDP respectively. On the contrary, the lowest health spending as a percentage of GDP is found in Luxembourg (5.8%), Romania (6.3%), and Poland (6.5%). Outside the E.U., health spending increased from 2019 to 2020 due to the health crisis, in the U.S.A. (2019: 16.7% and 2020: 18.8%) and the United Kingdom (2019: 9.9% and 2020: 12.2%).

Figure 2. Health spending as a share of GDP, in the European Union countries

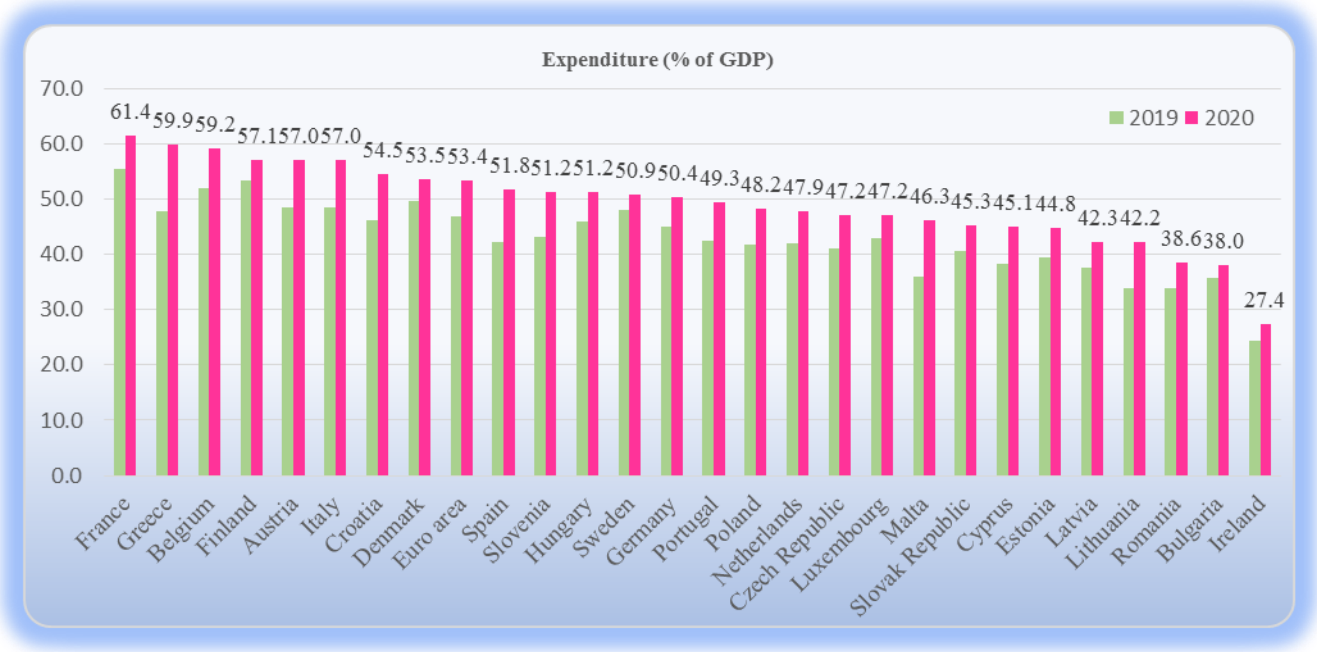


Source: Health spending (indicator) - OECD 2023

At the same time, on the demand side, the decline in exports and private consumption reduced GDP, while the huge increase in government spending tried to mitigate the problem. In particular, the Greek government, in addition to taking measures of a health nature, focused on fiscal policy measures on supporting employment and businesses. Public investments moved in the same supporting direction. Liquidity was maintained thanks to the extraordinary measures of the governments in both the private and public sectors (Bank of Greece 2021).

The government's support measures for the economy during the pandemic crisis have led to an increase in public expenditures worldwide. This reflects the extensive spending on health measures and income support for workers and businesses, and also the fall in GDP during the pandemic crisis. European countries tend to have higher public expenditures than others. So, in 2020, government expenditures rose as a share of GDP. Additional spending and forgone revenue, equity injections, loans and assets, and debt aimed to support households and businesses (OECD 2021). Government expenditures reached nearly 60% of GDP in France (61.4%), Greece (59.9%), Belgium (59.2%), and Finland (57.1%), surpassing the Eurozone average (53.4%). On the other hand, the lowest increases in government expenditures as a share of GDP are found in Ireland (27.4%), Bulgaria (38.0%), Romania (38.6%), and Cyprus (45.1%) (Figure 3). Also, in the advanced G-20 economies, an increase in public expenditure is recorded (2019: 38.6% and 2020: 47.0%). In particular, according to data from the IMF, a significant increase in public expenditures during the period of the health crisis is found in the United Kingdom (2019: 38.2% and 2020: 48.9%), the U.S.A. (2019: 35.7% and 2020: 45.3%) and Japan (2019: 37.3% and 2020: 44.6%). However, the percentage increase in public spending is more limited in emerging Asian economies such as China (2019: 34.2% and 2020: 35.4%) and India (2019: 27.4% and 2020: 31.1%).

Figure 3. Public expenditure as a share of GDP, in the European Union countries



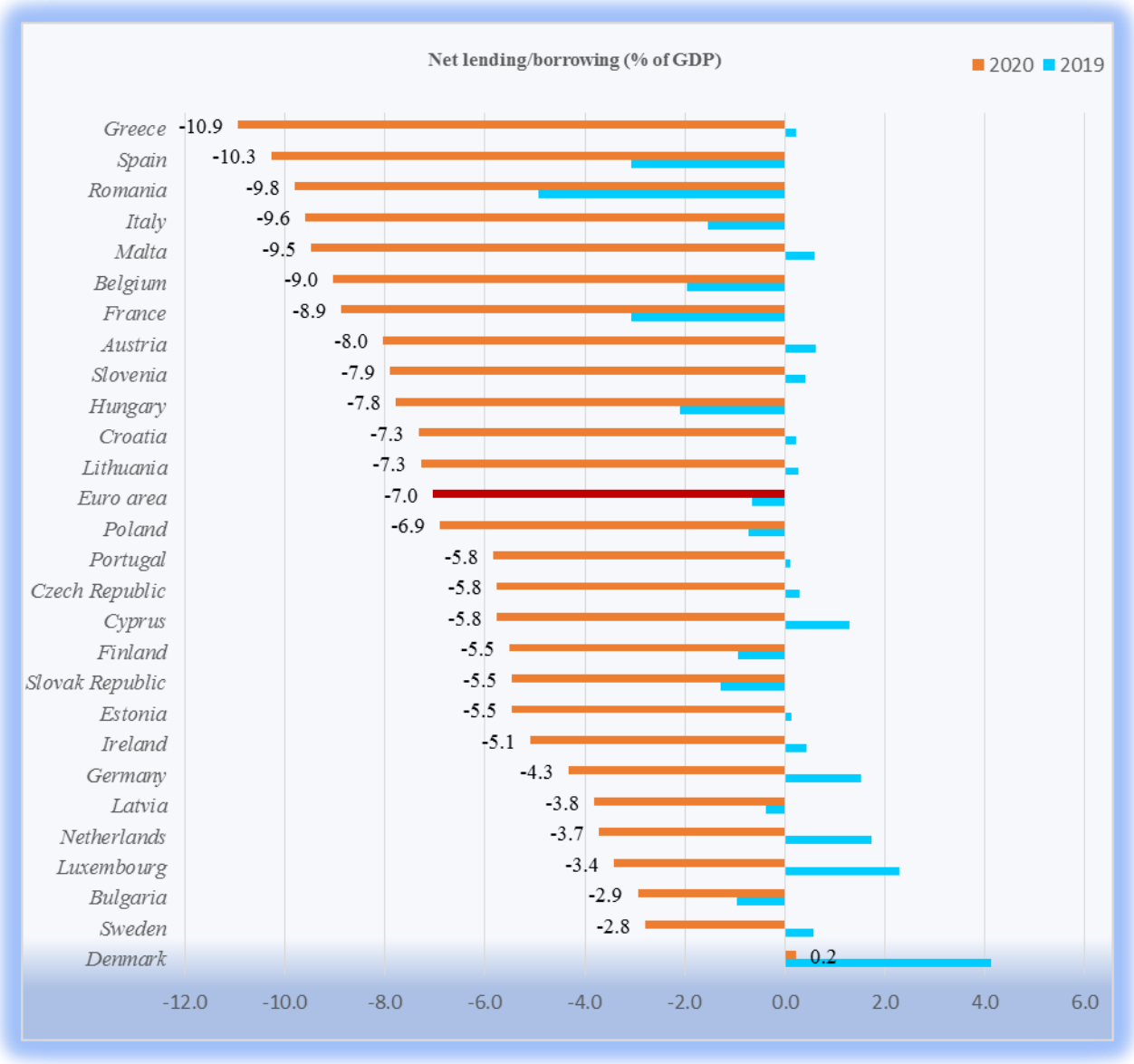
Source: IMF (ΔNT) 2022 – World Economic Outlook (October 2022).

4.2 The increase in fiscal deficit and debt in 2020

The global health crisis has forced governments to focus on stemming large economic losses in incomes and labour force so that the dimensions of the recession do not extend into the future. In Greece, this resulted in the general government surplus of 2019 turning into a deficit in 2020, while public debt as a percentage of GDP increased and deflationary trends emerged (IOBE 2021). The government's fiscal position worsened in 2020. The fiscal deficit of the Eurozone in 2020 amounted to 7.0% of GDP, compared to 0.6% of GDP in 2019, while at the same time, the public debt occupied 96.9% of GDP in 2020.

Figure 4 shows the net borrowing of the European Union Member States as a share of GDP during the two years 2019 and 2020. Deficits have risen significantly in 2020 as a result of pandemic responses. The budget deficit in the Eurozone averaged 7% of GDP in 2020 (2019: -0.7%). All countries had higher deficits than in 2019. Among countries with deficits of more than 8% of GDP, we can distinguish Greece (-10.9%), Spain (-10.3%), Romania (-9.8%), Italy (-9.6%), Malta (-9.5%), Belgium (-9.0%) and France (-8.9%). On the other hand, countries such as Lithuania (-7.3%), Croatia (-7.3%), Hungary (-7.8%), and Poland (-6.9%) showed a fiscal deficit close to the average of the Eurozone (-7.0%), while significantly limited, below 4%, was the fiscal deficit in Sweden, Bulgaria, Luxembourg, and the Netherlands.

Figure 4. Net lending/borrowing (% of GDP), in the European Union countries



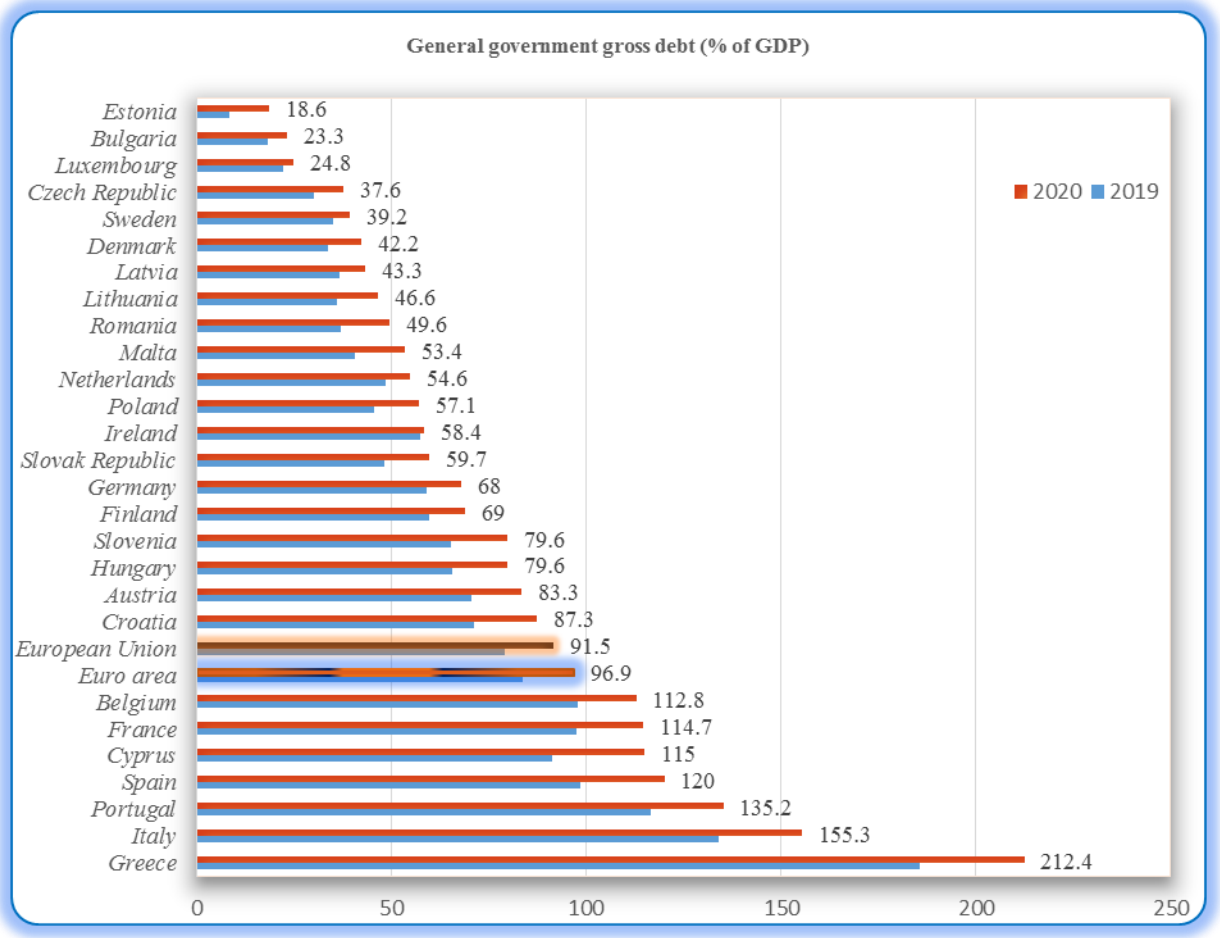
Source: IMF (ΔNT) 2022 – World Economic Outlook (October 2022).

Similarly, things are developed in other countries (U.S.A., Japan, etc.), with the public authorities activating fiscal measures to support economic activity. These fiscal measures, as well as the measures needed to protect workers against income losses, were activation measures introduced in a timely, decisive, and coordinated manner. A high fiscal deficit is necessary to stimulate economic growth and create jobs. Thus, outside the E.U., fiscal deficit has sharply increased in the U.S.A. (-14.5%), the United Kingdom (-12.8%), India (-12.8%), China (-9.7%), and Japan (-9.0%).

Then, the General Government Gross Debt (% of GDP) rose as the fiscal deficit grew to pay the COVID-19 response measures. At the European Union level, the average general government gross debt rose from 79.1% of GDP in 2019 to 91.5% in 2020 (Figure 5). Greece is among the countries with a particularly high debt-to-GDP ratio of the general government, surpassing the European average. In 2020, the national debt of Greece amounted to approximately 212.4% of the GDP, followed by Italy (155.3%), Portugal (135.2%), Spain

(120.0%), and Cyprus (115.0%). Close to the E.U. average (91.5%) was the gross debt of Croatia (87.3%), Austria (83.3%), Hungary (79.6%), Finland (69.0%), and Germany (68.0%). Finally, significantly restricted remained government debt ratio levels in Estonia (18.6%), Bulgaria (23.3%), and Luxembourg (24.8%) compared to the European average.

Figure 5. General government gross debt as a share of GDP, in the European Union countries



Source: IMF (ΔNT) 2022 - World Economic Outlook (October 2022).

Internationally, the gross debt of countries increased during the health crisis. Indicatively, it is stated that the debt of countries such as the United Kingdom (2019: 83.9% and 2020: 102.6%) and the U.S.A. (2019: 108.8% and 2020: 134.5%) stood out, with Asian countries like China (2019: 57.2% and 2020: 68.1%) and India (2019: 75.1% and 2020: 89.2%) to follow at moderate levels.

4.3 The policy interventions in the E.U.

To deal with possible serious and generalized effects of the COVID-19 pandemic on the economy, a series of restrictive measures were taken by the European Commission in 2020. The set of financial instruments and decisions of the European institutions, mainly regarding the European recovery instrument Next Generation EU (NGEU) and the Multiannual Financial Framework acted as an important lever to strengthen the economies of the Member States. The facilitation policy of the European Commission played a decisive role, in the increase in the rate of lending to vulnerable companies. Indicatively, it is mentioned that, despite differences between the Member States, the expansionary nature of the fiscal policy of the Eurozone converged towards the limitation of the economic consequences of the pandemic. Eurozone fiscal interventions and liquidity measures reached 4% and 19% of GDP, respectively (Bank of Greece 2021). More generally, countries have taken measures to limit the spread of the virus, and even more to stop the virus. Substantial targeted policies are needed to stimulate demand and liquidity to support the economy. Furthermore, these policies and measures aimed to help businesses survive the crisis and to promote employment. Supportive measures include income transfers, unemployment benefits, wage subsidies, government guarantees, loans, equity participation, and suspension of tax and social security contributions. The above aids and strategies are depending on the intensity and duration of the crisis and the fiscal capabilities of each State.

5. Conclusion

The COVID-19 pandemic has been characterized as the largest, unprecedented "exogenous shock" worldwide and has posed challenges to the global economy since 2020. This health crisis has left a deep imprint on the economy and society.

The very nature of the disease's contagiousness creates a direct negative externality that is impossible to address through the price system. This means that a person's decision to undertake any activity that might expose someone else imposes a cost on others that is not borne by the person who causes it. To limit the spread of the disease, the government's public intervention imposed social distancing with the implementation of lockdown (quarantines and closure of businesses, etc.). Also, the measures caused a second form of externalities related to the indirect negative consequences at the macroeconomic level, such as the reduction of economic activity and the swelling of the public debt (Stiglitz 2021). Indeed, the contraction in economic activity arising from COVID-19, with a 3% decrease in global GDP, is attributed to the "double shock" suffered by supply (declining production) and demand (declining consumption). The consequences of the pandemic have been particularly felt for sectors such as trade, land, air and sea transport, education, and culture, with numerous events of business-commercial interest, as well as cultural content being postponed or canceled. The path of recovery, which the Greek economy had begun to show since 2017, was interrupted by the pandemic crisis. To deal with market failures, States activated measures of economic policy intervention. As a result, policymakers are now facing extraordinary challenges: government budget deficits as well as public debt are rising to extremely high levels in many countries.

Furthermore, the COVID-19 pandemic highlights the interaction between economics and political science, which is also the subject of Political Economy. The government's response to the pandemic outlines the policy choices of countries in the context of global cooperation. After all, every pandemic requires a coordinated, international response, as its microbial source is impossible to be limited within the borders of a country. The establishment of international organizations such as the World Health Organization aspires to be a brake on a potential outbreak of a global health crisis through the establishment of specific directives or guidelines. In the period that followed 2021, a gradual recovery of the economy and a return to normality was observed, due to the supportive measures of governments during the health crisis. However, the rate of recovery does not seem to show

homogeneity between countries and depends on the effectiveness of dealing with possible mutations of the virus, the speed of vaccination of the population as well as the degree of harmonization of the economic policy of the States at the national level with the above guidelines (Goodman *et al*. 2010). These guidelines must include public health recommendations and take into account economic parameters and potential scenarios of political developments and challenges.

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